AD-785 195

DEVELOPMENT OF STRETCH FABRIC FOR PARACHUTE CANOPIES

John Skelton, et al

Fabric Research Laboratories, Incorporated

Prepared for:

Aeronautical Systems Division

August 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
stretch fabric: parachute canopies; air permeability; biaxial stress; fabric mechanical performance.						

ia

AD 785195

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Fabric Research Laboratories
1000 Providence Highway
Dedham, Massachusetts 02026

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE

Development of Stretch Fabric for Parachute Canopies

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report; July 2, 1971 to April 17, 1974

5. AUTHOR(S) (First name, middle initial, last name)

John Skelton, Norman J. Abbott

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1974	52	3

8a. CONTRACT OR GRANT NO.
F33657-71-C-1168

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

ASD-TR-74-26

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Life Support System Program Office
Aeronautical Systems Division
WPAFB

13. ABSTRACT

A new lightweight one-way stretch parachute canopy fabric was developed for use in personnel parachutes, whose mechanical properties are equal to the conventional 1.1 oz/sq yd canopy fabric, but which shows a greatly increased air permeability under the loading conditions experienced during deployment. The variation of permeability with pressure differential for a range of biaxial loading conditions was investigated for the new fabric and for other canopy fabrics, and it was shown that for maximum effectiveness the easy stretch direction of the new fabric should be oriented parallel to the direction of maximum stress in the parachute canopy.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

DEVELOPMENT OF STRETCH FABRIC FOR PARACHUTE CANOPIES

J. Skelton
N. J. Abbott

Approved for public release; distribution unlimited.

FOREWORD

This report was prepared by Fabric Research Laboratories, Dedham, Massachusetts under U.S. Government Contract No. F33657-71-C-1168; the work was sponsored by the Life Support System Program Office, Aeronautical Systems Division and was under the technical direction of the Air Force Materials Laboratory, Air Force Systems Command, with Mr. P. Opt (MBC) acting as project engineer.

This report covers work conducted from July 2, 1971 through April 17, 1974.

The authors wish to express their appreciation to Dr. Milton M. Platt of Fabric Research Laboratories for handling contractural matters and for many helpful discussions throughout the course of the work.

The report was released by the authors April 1974.

This technical report has been reviewed and is approved.

William M. Quinn, Colonol, USAF
System Program Director
Life Support System Program Office
Deputy for Subsystems

ABSTRACT

A new lightweight one-way stretch parachute canopy fabric was developed for use in personnel parachutes, whose mechanical properties are equal to the conventional 1.1 oz/sq yd canopy fabric, but which shows a greatly increased air permeability under the loading conditions experienced during deployment. The variation of permeability with pressure differential for a range of biaxial loading conditions was investigated for the new fabric and for other canopy fabrics, and it was shown that for maximum effectiveness the easy stretch direction of the new fabric should be oriented parallel to the direction of maximum stress in the parachute canopy.

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

Preceding page blank

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

SECTION I

INTRODUCTION

Emergency escape personnel parachutes used by aircrewmen of high performance aircraft are required to operate over a wide range of deployment speeds, and the performance characteristics for low speed deployment are in direct conflict with those for high speed deployment. For a parachute to function efficiently under low speed deployment conditions, the extreme case of which is represented by an ejection from a stationary aircraft, it is necessary to use a canopy fabric with low air permeability in order to guarantee a rapid pressure buildup and a prompt inflation. Under high speed deployment conditions, however, a fabric with high air permeability is needed in order to reduce the opening shock forces, which can be large enough to cause structural failure of the parachute and injury to the crewman.

Since the pressure differential across the fabric, and hence the tensile stress on the fabric elements, increases with increasing deployment speed, a possible resolution of the conflicting permeability requirements can theoretically be achieved by the use of a fabric which will stretch under the deployment loads, giving an increased air permeability as a consequence of the increased area of the inter yarn spaces. This stretch must be rapidly recoverable, so that the permeability will again fall to a low value during the steady state descent, when the aerodynamic pressures are small.

Two approaches have been made to the design of fabrics with the appropriate characteristics. The first approach [1] attempted to use the intrinsically high deformability of a tricot knit structure to achieve the design objectives. This was reasonably successful in that fabrics were developed which reduced the shock loading, but it proved very difficult to produce a lightweight knit fabric with the correct low permeability under small pressure differentials. Other difficulties were encountered with tensile and tear strength in the wale direction. The second approach used woven fabrics with stretch capability, and was also moderately successful. The initial work was carried out by Irving Air Chute [2], under the joint sponsorship of the U. S. Air Force and the Canadian government, and involved the screening of commercially available stretch materials and the selection of the most promising material for incorporation into parachute canopies. The fabric chosen as a result of this study was a 3.6 oz/sq yd one-way stretch nylon fabric; parachutes containing various amounts of this material were made up and were tested by the Air Force Flight Test Center, Edwards Air Force Base [3]. The test data verified the feasibility of the stretch concept, but it was clear that commercially available fabrics were far from satisfying the combination of weight, strength, and permeability characteristics required in the optimum stretch fabric for parachute canopies; the work described in this report was concerned with the development of new stretch fabrics with characteristics specifically designed to satisfy those requirements, and with the commercial production of sufficient fabrics to permit further extensive evaluation of the stretch canopy concept.

SECTION II

CHARACTERIZATION OF CURRENT MATERIALS

In the drop test program carried out by the Air Force Flight Test Center, Edwards Air Force Base, the opening characteristics of a standard C-9 28 ft diameter parachute were compared with the characteristics of modified C-9 parachutes incorporating stretch fabric in some sections of each gore. A good starting point for the development of improved stretch fabrics for this application is the characterization of the mechanical properties of the fabrics used in the parachutes which were drop-tested. A considerable body of performance data exists for these parachutes, but very little is known about the mechanical behavior of the stretch fabrics. Test parachutes were available with three panel configurations as shown in Figure 1. A configuration II parachute was obtained from Wright-Patterson Air Force Base and was used as the source of test specimens.

Panels 1 and 2 of the parachute were made from standard MIL-C-7020 Type I, 1.1 oz/sq yd nylon fabric. This fabric is woven from low twist, 30 denier, 10 filament, high tenacity nylon yarns; sections along warp and filling yarns are shown in Figures 2(a) and 2(b) respectively. The warp yarns are somewhat rounded in cross section partly as a result of the tensions imposed during weaving and partly as a result of the 5 turns per inch of twist called for in the fabric specification. The filling yarns are ribbon-like and are in side-by-side contact at the crossover points in the central plane of the fabric. As a consequence of the more rounded cross sectional shape of the warp yarns, the filling yarns are more highly crimped, and thus under uniaxial tensile load the fabric has a lower modulus and a greater elongation to break in the filling direction; this is shown in Figure 3.

Panels 3 and 4 of the parachute were made from a stretch fabric described as Pattern No. W-112, 3.6 oz/sq yd nylon. The material removed from the drop-tested parachute weighed 3.5 oz/sq yd, and consisted of 232 ends per inch of 70 denier, 34 filament, regular tenacity nylon yarn, and 72 picks per inch of a composite yarn made by wrapping a 40 denier, 13 filament, regular tenacity nylon yarn on a 70 denier Spandex core. Sections along the warp and filling yarns have much more crimp than the filling yarns; this is a result of the large number of warp yarns per unit width, which can only be accommodated in the fabric if they lie side-by-side around the essentially straight filling yarns. This type of structure gives a thick fabric and it can be seen from the sections of the two fabrics (which were photographed at the same magnification) that the stretch fabric is approximately 3.5 times as thick as the 1.1 oz/sq yd fabric. The tensile behavior of the stretch fabric under uniaxial load is shown in Figure 5: the warp direction has an elongation to break similar to the filling direction of the 1.1 oz/sq yd fabric; in the filling direction the elongation to break is very great as a result of the stretch of the covered Spandex yarn. Values of the breaking loads and elongations of the two fabrics are given in Table 1.

Preceding page blank

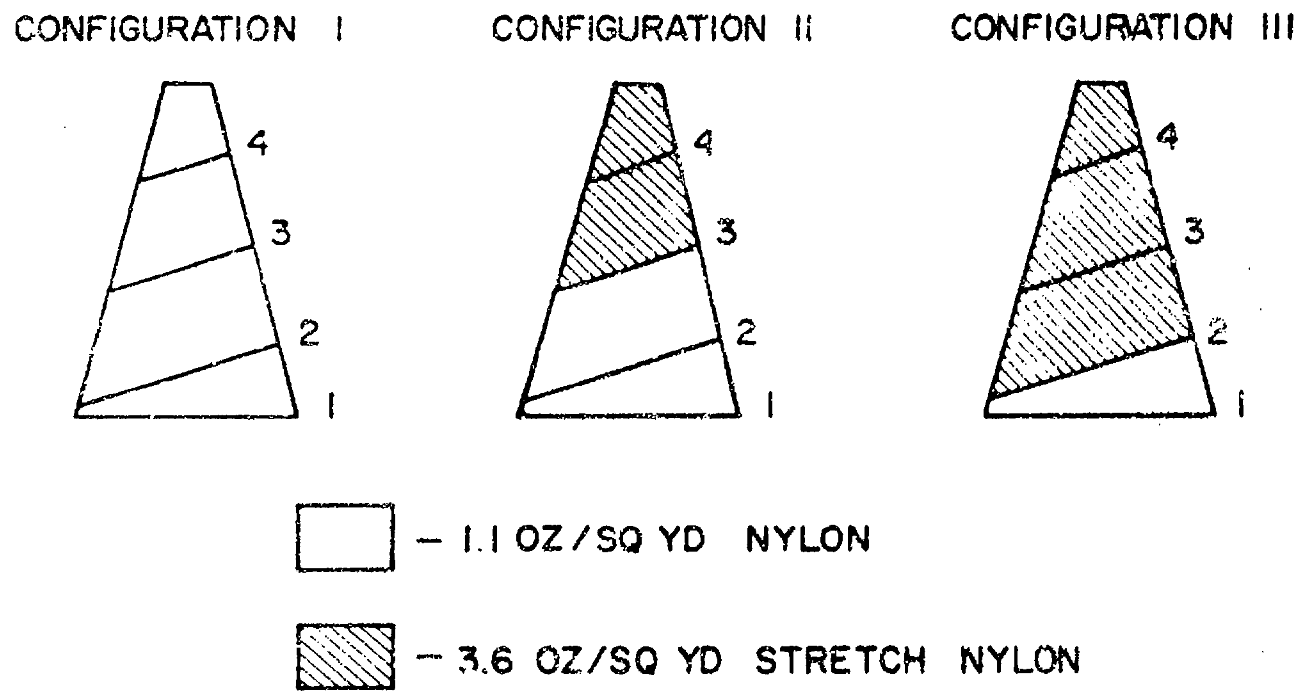
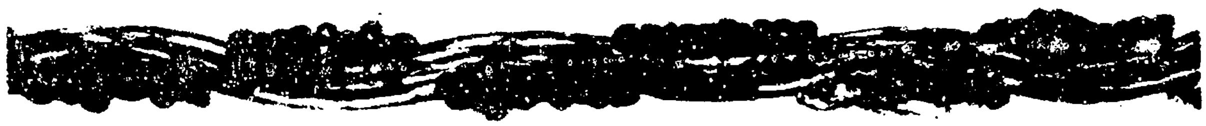


Figure 1. Test Parachute Panel Configurations



(a)

Figure 2. Sections Along (a) Warp, and (b) Filling Yarns of Conventional 1.1 oz/sq yd Nylon Canopy Fabric

(b)

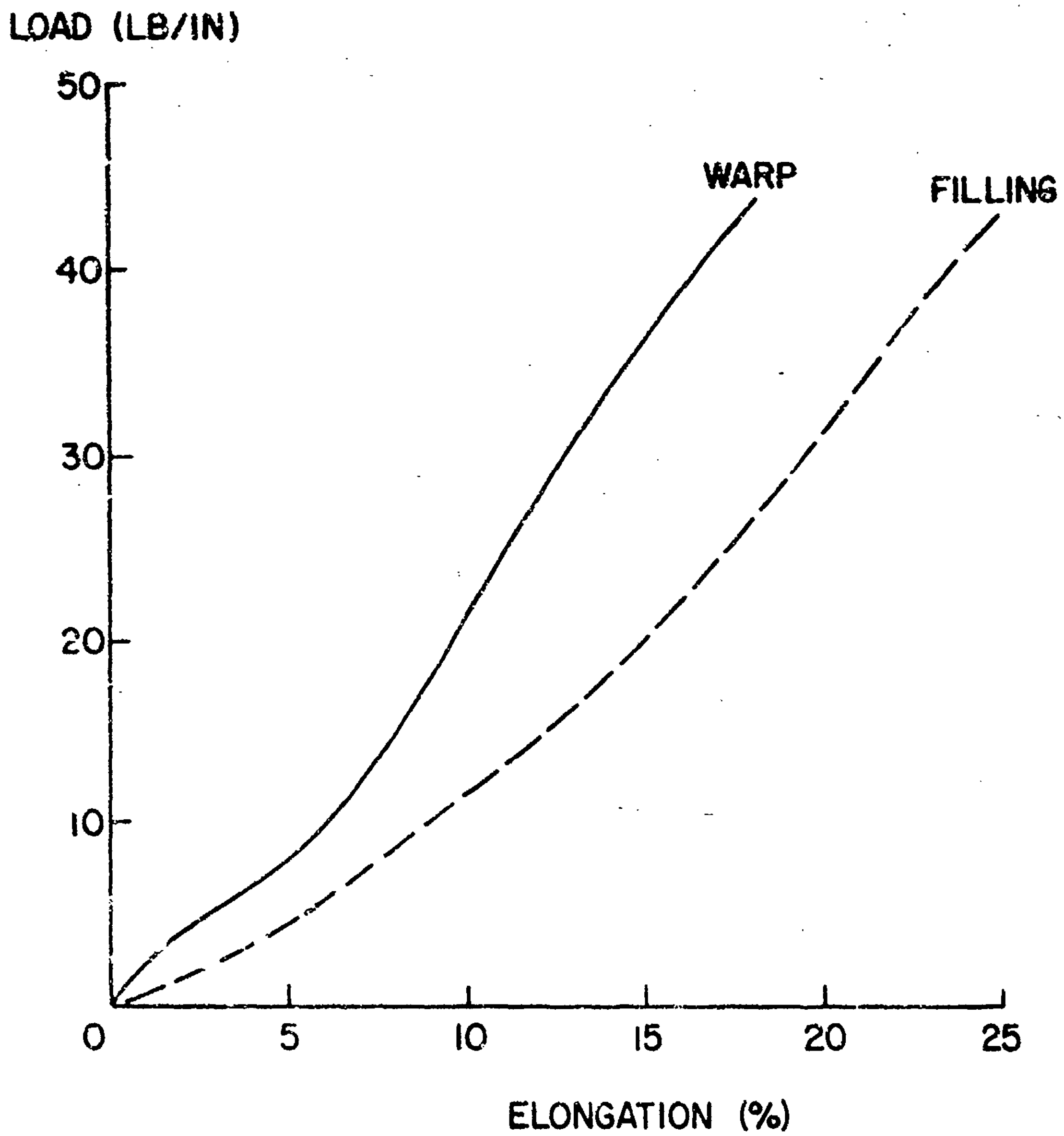


Figure 3. Uniaxial Load-Elongation Behavior of 1.1 oz/sq yd Nylon Canopy Fabric

(a)

Figure 4. Sections Along (a) Warp, and (b) Filling Yarns of 3.6 oz/ sq yd Stretch Nylon Canopy Fabric

(b)

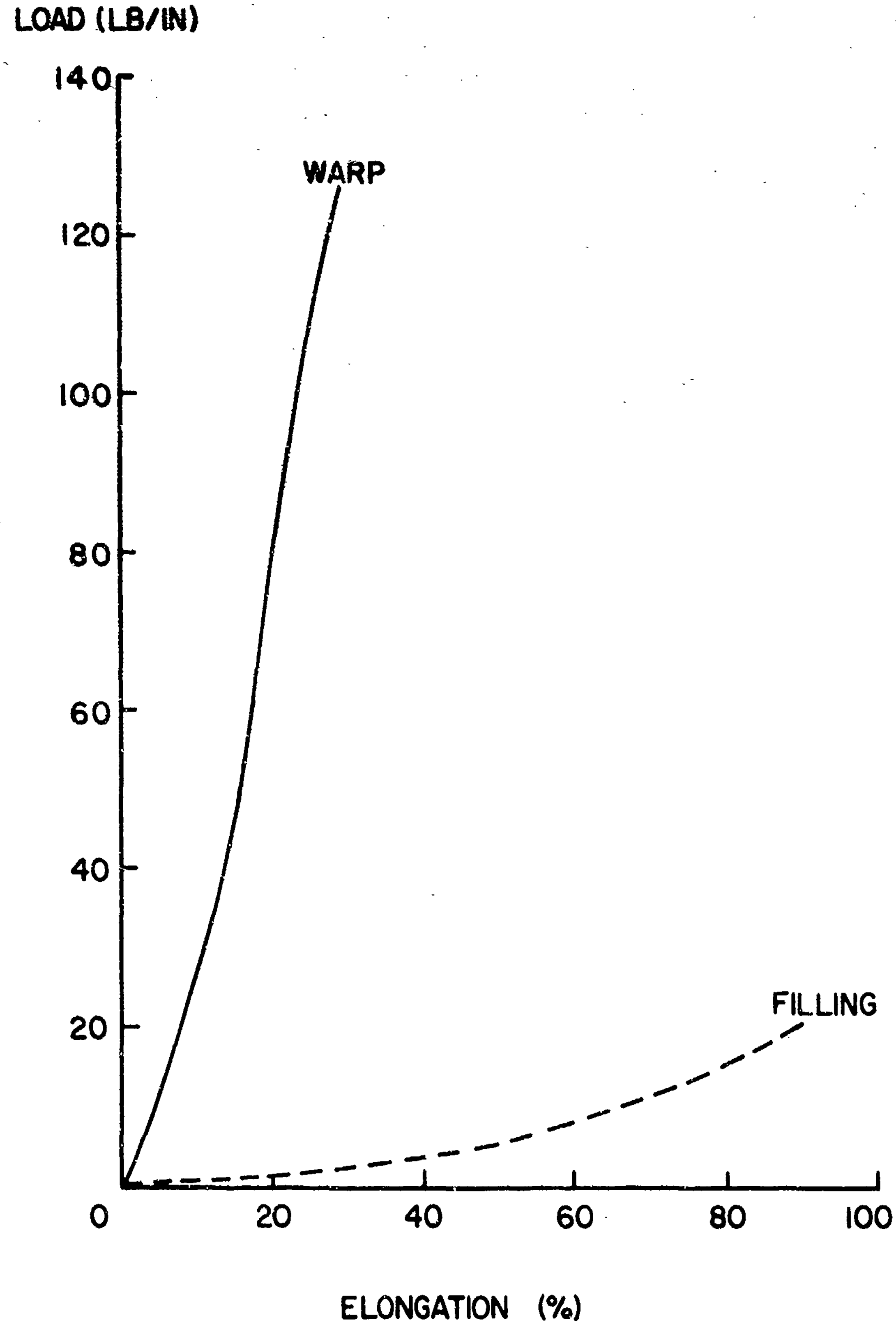


Figure 5. Uniaxial Load Elongation Behavior of 3.6 oz/sq yd Stretch Nylon Canopy Fabric

TABLE 1

TENSILE PROPERTIES OF CANOPY FABRICS

	Breaking Load (lb/in)		Breaking Elongation (%)	
	Warp	Filling	Warp	Filling
1.1 oz/sq yd nylon	44.1	43.5	18.0	25.2
3.5 oz/sq yd stretch nylon	126.4	20.0	29.1	89.4

Inspection of the data of Table 1 immediately shows some of the deficiencies of this stretch fabric. The specification requirements for breaking load for the 1.1 oz/sq yd fabric, which ideally should also be met by the stretch fabric, are 40 lb/inch minimum. In the warp direction this is exceeded by a factor of 3 in the stretch fabric, and the total denier per inch of the warp yarns could be reduced by this factor without prejudice to the tensile behavior. In the filling direction the strength is supplied mainly by the nylon wrapping yarns, and the breaking load is only about half the required value. This is in accord with the performance to be expected on the basis of the constructional features discussed above: the 1.1 oz/sq yd fabric has 120 picks per inch of 30 denier yarns, giving a total denier per inch of 3600; the total denier per inch of nylon yarn in the filling direction of the stretch fabric is 2880, and if allowance is made for the lower tenacity of the yarn in this fabric, the measured ratio of breaking loads is obtained.

Both the 1.1 oz/sq yd fabric and the stretch fabric are oriented in the bias direction in the gore of the C-9 parachute canopy and this considerably modifies the response of the fabrics to the stress set up during deployment. The bias load-elongation characteristics of the two fabrics are shown in Figure 6; the differences between the two fabrics are greatly reduced in this configuration. The basic mode of deformation for the fabrics at low stress levels is by fabric shear. This type of deformation has a great effect on the geometry of the fabric interstices, and hence on the air permeability. Measurements were made of the air permeability of the standard 1.1 oz/sq yd fabric and the stretch fabric over a wide range of pressure differentials (0.5-12 inches of water) and for different extents of shearing. A modified Frazier permeometer was used for these measurements. Results are shown in Figure 7. The first point of interest is the extremely low value of the permeability of the unsheared stretch fabric. At a pressure differential of 0.5 inches of water, the 1.1 oz/sq yd fabric has a permeability of 120 cu ft/min/sq ft while the stretch fabric under the same pressure differential has a permeability of only 14.3 cu ft/min/sq ft, probably as a result of the close packing of the high denier warp yarns which gives a thick, dense fabric structure. The difference between the two fabrics

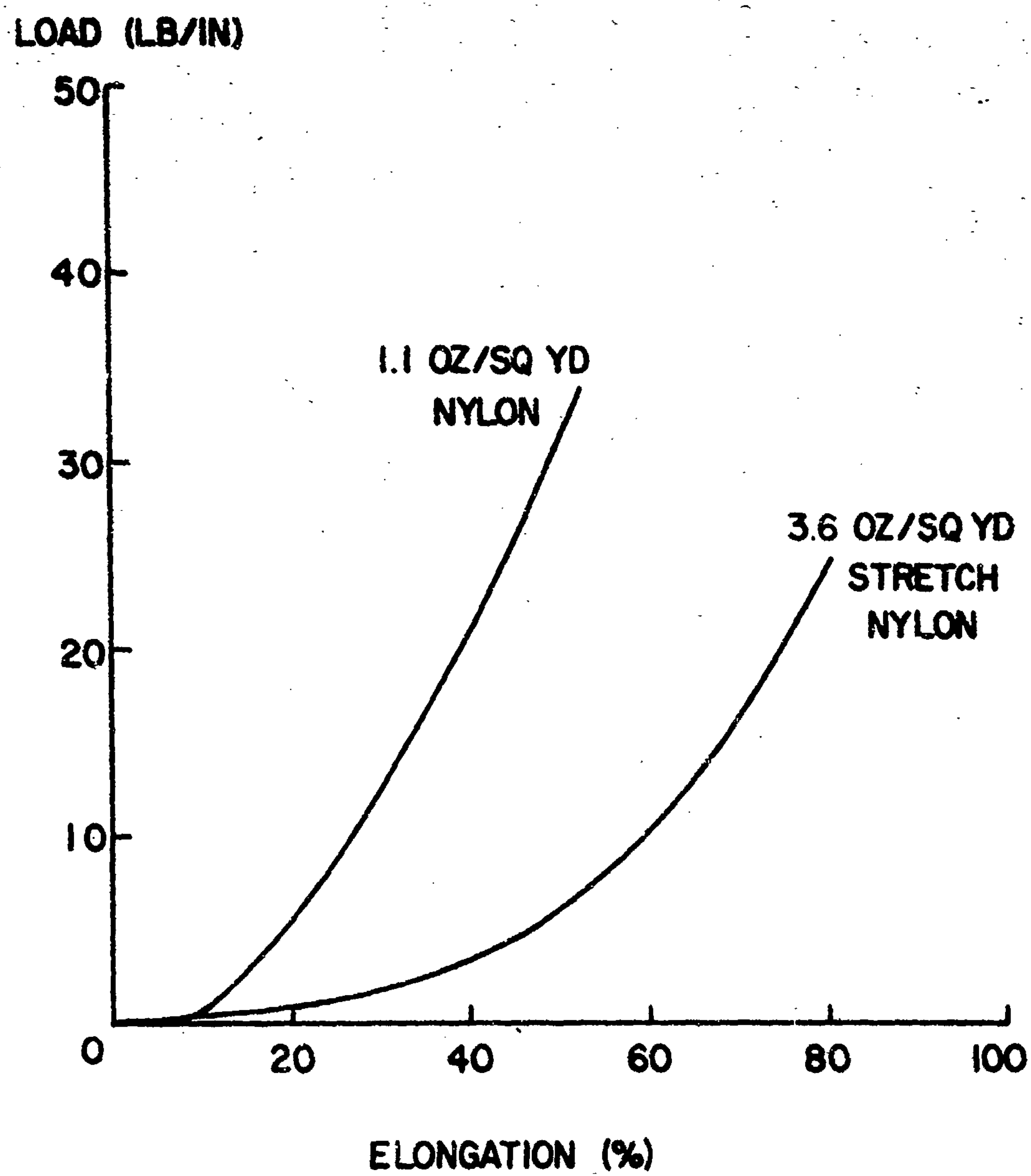


Figure 6. Bias Load-Elongation Behavior of Canopy Fabrics

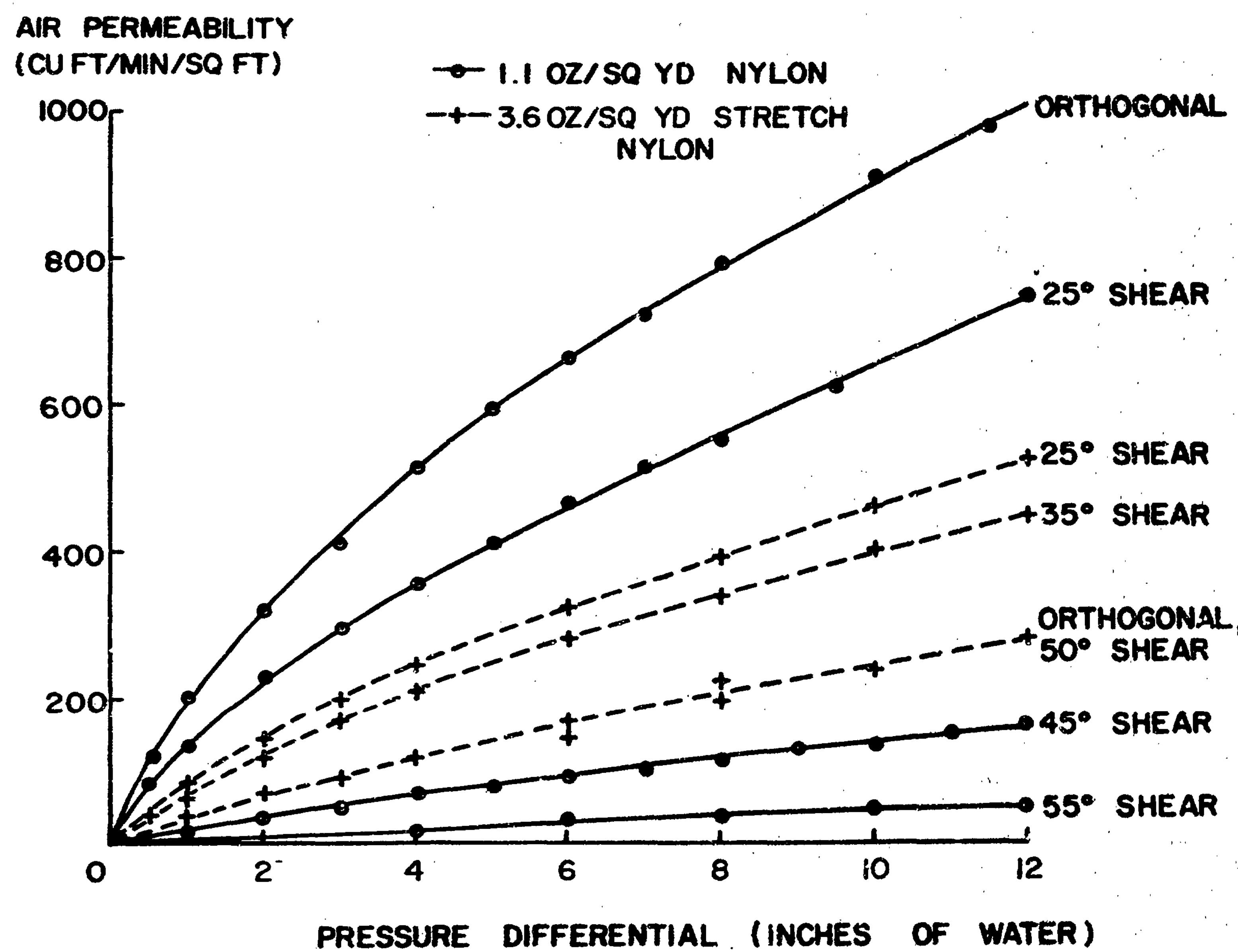


Figure 7. Air Permeability of Canopy Fabrics Sheared to Various Extents

persists at all pressure differentials, the values at 12 inches of water being approximately 1000 cu ft/min/sq ft for the 1.1 oz/sq yd fabric and 276 cu ft/min/sq ft for the stretch fabric. Other interesting differences between the two fabrics are seen when the data for the sheared configurations are studied. In the standard canopy fabric the application of increasing shear strain leads only to a diminution of the area of the inter-yarn spaces, and hence to a monotonic decrease in the air permeability. In the stretch fabric, however, an additional mechanism of deformation, namely filling yarn extension, is possible, which can lead to an <u>increase</u> in the area of the inter-yarn spaces. Accordingly, we see that the application of increasing shear stress and strain leads to an initial increase in permeability, followed by a subsequent decrease.

Clearly the commercial stretch fabric used in the drop-tested parachutes does not meet the requirements of the basic concept, which requires a permeability equal to or less than that of the 1.1 oz fabric at 0.5 inches of water, and a permeability substantially greater than the 1.1 oz fabric at 12 inches of water. At low pressure differentials the permeability is within specification, but is so low as to make impossible the required permeability at high pressure differentials; a stretch fabric with a permeability very similar to the 1.1 oz/sq yd fabrics is probably needed if those permeability requirements are to be met.

We may now assess some of the design changes that can be made to improve the performance of the commercial stretch fabric. The fabric is very unbalanced in its properties, both in extensibility and load bearing capacity, and would certainly be improved if the properties could be adjusted to be more nearly equal in the two directions. Preliminary calculation indicated that this could be achieved with some saving of weight, since the warp direction is overdesigned for load bearing capacities by a much greater factor than the underdesign of the filling. Any saving in weight would reduce the deployment snatch force, as is indicated by the drop-test data on the various parachute configurations [3].

The reduction in opening shock, which should be influenced by the porosity of the fabric, was disappointingly small for the drop-tested stretch parachute. The measurements of air permeability show the probable reason for this: the stretch fabric, though increasing in permeability with pressure differential at a faster rate than the regular fabric, has an initial permeability that is so low as to negate the value of the stretch. The permeability at low pressure differences can be increased to that of the 1.1 oz/sq yd fabric by reduction of fabric density and thickness and these adjustments can be accomplished at the same time as the equalization of directional properties. Ideally the stretch yarns should run in both directions, in order to give a fabric with balanced tensile characteristics. However, it is difficult to weave fabrics with controllable properties with stretch yarns on both directions, and as a practical alternative it should be possible to use a one-way stretch fabric to give the desired permeability characteristics <u>if the direction of easy stretch can be oriented in the direction of principle stress</u>.

In order to explore this concept further, the air permeability characteristics of the stretch fabric were investigated for uniaxial load conditions in which the load was applied in the easy stretch direction. Results are given in Figure 8, which should be compared with the data of Figure 7 where the air permeability for the same fabric stretched uniaxially in the bias direction are shown. At any given pressure differential the air permeability increases much more rapidly with stretch when the load is applied parallel to the stretch direction than when the load is applied in the bias direction. In the latter case there is shear deformation of the fabric, which tends to decrease the fractional open area at high stretch levels while in the former case the area is increased monotonically with increasing stretch. It is clear from these results that one-way stretch fabric would be more suitable for the intended use if it were oriented so as to take advantage of the stretch, and high permeability capacity.

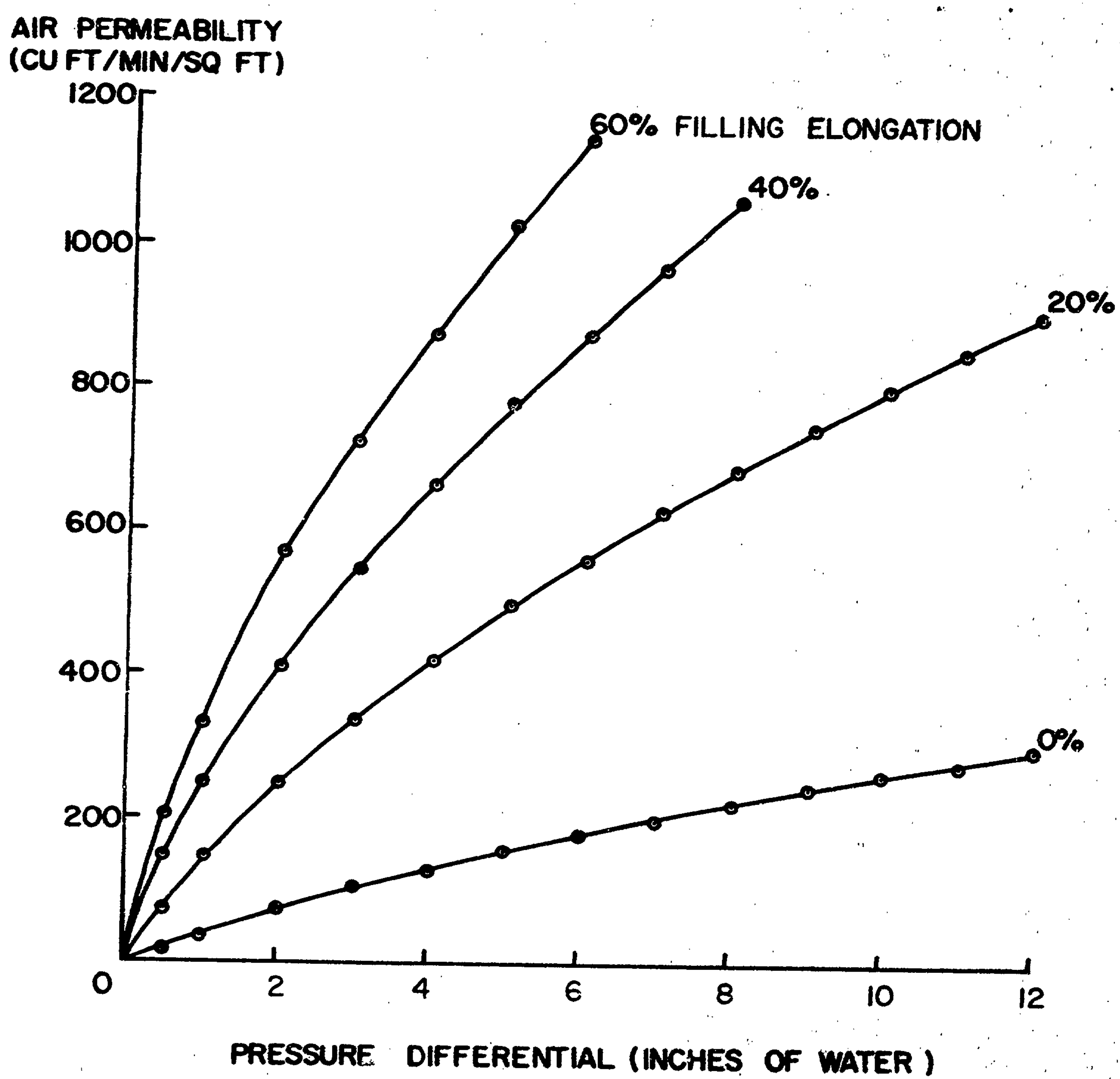


Figure 8. Air Permeability of 3.6 oz/sq yd Stretch Fabric at Various Filling Elongations

SECTION III

DEVELOPMENT OF LIGHTWEIGHT STRETCH FABRICS

The first step in the development of lightweight stretch fabrics is the production of suitable yarns. The requirement of rapid, and essentially complete, recovery of the fabric from tensile strain strongly suggested the use of wrapped yarns, similar to those used in the drop-tested stretch fabrics. Following discussion of the end use requirements and the availability of commercial materials, a wide selection of lightweight wrapped yarns was produced by JRA Industries, Inc., Ashboro, North Carolina; constructional details of the yarns are given in Table 2.

The Spandex core yarns used in these yarns was manufactured by the Globe Manufacturing Co., Fall River, Mass. This material was recommended by JRA as the most suitable of the available Spandex yarns from point of view of resistance to UV degradation. The nylon and polyester yarns were the lightest high tenacity yarns currently produced. The nylon yarn had a measured denier of 29.4 and a breaking tenacity of 5.51 gm/denier; the polyester had a measured denier of 44 and a breaking tenacity of 6.6 gm/denier. Some mechanical properties of the wrapped yarns are shown in Table 3. A preliminary investigation showed that a 10-gm load was sufficient to remove the easy stretch from the yarns; accordingly the denier was found using the length of the yarns under a 10-gm load was the basis for calculation. The effect of cyclic stressing was investigated by mounting the yarns under a 10-gm load and cycling the load 5 times between 10 gm and 100 gm. The slope of the curve of the fifth recovery cycle at a load level of 10 gm was found as a measure of the recovery modulus of the yarn. In addition the elongation of the specimens after 1 cycle and 5 cycles, and the breaking load and elongation after 5 cycles were found. All elongations were based on the initial gauge length under the 10-gm load.

Examination of the data contained in Table 3 shows that only relatively small differences exist between the various experimental yarns made with the same cover yarn, but that considerable differences exist between the yarns with nylon and with polyester covers. The higher tenacity of the polyester wrapped yarn, and the effect of the higher recovery modulus of the polyester is apparent in the smaller values of additional elongation produced by load cycling. Within groups, the presence of a heavier core yarn leads to a slight reduction in gpd of the wrapped yarns, as would be expected, since the core adds weight but little strength. There are some puzzling differences between the responses of the nylon and the polyester to changes in structure. For the nylon there is a slight increase in tenacity with increasing number of wraps per inch, while the polyester shows the opposite tendency. On cycling the nylon yarns are generally reduced in strength slightly and the polyester yarns show small strength increases in several cases. There are no obvious reasons why all the experimental yarns might not be suitable for the canopy application, and consequently there are no very strong reasons for selecting one particular yarn over another. The number 3 yarns, with 21.3 wraps per inch, from each of the groups were chosen for

TABLE 2

CONSTRUCTIONAL DETAILS OF EXPERIMENTAL WRAPPED YARNS

Yarn Designation	Cover Yarn	Spandex Core Yarn Denier*	Wraps/Inch
1-A-50	30 denier	50	33.9
2-A-50	nylon, Du		26.8
3-A-50	Pont type		21.3
4-A-50	330		16.0
1-A-87		87	33.9
2-A-87			26.8
3-A-87			21.3
4-A-87			16.0
1-A-100		100	33.9
2-A-100			26.8
3-A-100			21.3
4-A-100			16.0
1-B-50	40 denier	50	33.9
2-B-50	polyester,		26.8
3-B-50	Hystron		21.3
4-B-50	type 732		16.0
1-B-87		87	33.9
2-B-87			26.8
3-B-87			21.3
4-B-87			16.0
1-B-100		100	33.9
2-B-100			26.8
3-B-100			21.3
4-B-100			16.0

*A draft of 4 was used in the production of all the yarns; the numbers in the table represent the deniers of the <u>unstretched</u> yarns.

TABLE 3

MECHANICAL PROPERTIES OF EXPERIMENTAL WRAPPED YARNS

Yarn Designation	Denier Under 10-gm Load	Breaking Load (gm)	Breaking Tenacity (gm/den)[a]	Recovery Modulus[b] on 5th Cycle (gm/% Elong)	Additional[c] Elong on Cycling (%) 1st	5th	Breaking Load after 5 Cycles (gm)	Breaking[d] Elong after 5 Cycles (%)
1-A-50	39.9	191.2	4.79	4.8	4.2	4.9	172	18.2
2-A-50	38.1	199.0	5.22	5.0	4.3	5.1	188	23.0
3-A-50	40.4	189.5	4.70	4.8	3.8	4.5	180	20.1
4-A-50	38.4	193.0	5.02	5.4	3.7	4.5	182	19.9
1-A-87	44.5	210.8	4.74	4.6	4.1	4.8	179	17.7
2-A-87	46.2	201.5	3.36	4.8	4.3	5.1	187	20.2
3-A-87	39.4	187.2	4.75	4.6	3.9	4.6	182	20.1
4-A-87	45.2	202.0	4.47	5.2	3.4	4.1	193	22.2
1-A-100	43.7	203.0	4.64	4.4	4.8	5.6	185	19.3
1-A-100	47.8	206.3	4.31	4.8	4.7	5.4	200	23.4
3-A-100	45.0	194.3	4.32	4.4	4.1	4.9	189	23.5
4-A-100	48.2	202.6	4.12	4.4	3.9	4.6	196	22.9
1-B-50	50.4	255.4	5.06	18.2	2.3	2.8	238	9.9
2-B-50	52.5	289.3	5.51	20.0	2.0	2.4	321	11.7
3-B-50	49.4	323.0	6.54	23.8	1.3	1.7	321	10.2
4-B-50	46.5	321.4	6.91	22.4	1.3	1.6	316	9.4
1-B-87	56.7	295.8	5.21	14.8	2.9	3.4	215	9.9
2-B-87	60.4	279.0	4.62	15.2	2.5	3.0	310	11.2
3-B-87	63.4	312.1	5.06	20.0	1.8	2.1	312	10.5
4-B-87	59.0	318.8	5.40	20.6	1.7	2.1	305	10.7
1-B-100	65.1	287.0	4.41	12.6	2.2	2.7	314	12.7
2-B-100	64.6	345.3	5.34	14.8	2.3	2.7	324	11.9
3-B-100	65.2	297.1	4.55	20.0	1.9	2.1	318	10.9
4-B-100	51.4	338.3	6.58	16.4	1.9	2.3	341	11.4

a) Length measurement under 10-gm load, b) Slope of fifth recovery curve at 10-gm load, c) Based on 10 inch initial gauge length under 10-gm load. Cycled between 10-gm and 100-gm, d) Based on 10 inch initial gauge length under 10-gm load.

further study: this choice of wrap frequency allowed adjustment either upward or downward if subsequent investigation showed that 21.3 wraps was unsuitable for any reason. In addition the effect of wrap frequency within a single group, namely the polyester yarns with the 87 denier core, was studied in more detail. Accordingly, larger quantities of these selected yarns were obtained from JRA for further characterization and weaving trials.

In the second phase of the yarn selection study, approximately 10,000 yards of each of the yarns shown in Table 4 were wrapped.

TABLE 4

CONSTRUCTIONAL DETAILS OF SELECTED EXPERIMENTAL YARNS

Yarn Designation	Cover Yarn	Spandex Core Yarn Denier	Wraps/Inch
3-A- 50	30 denier nylon,	50	21.3
3-A- 87	DuPont type 330	87	21.3
3-A-100		100	21.3
3-B- 50	40 denier polyester,	50	21.3
3-B- 87	Hystron type 732	87	21.3
3-B-100		100	21.3
1-B- 87		87	33.9
4-B- 87		87	14.0

The denier of each yarn under a 10-gm tension was remeasured, and the breaking loads were found; results are shown in Table 5, and are in excellent agreement with the measurements made previously on the initial samples.

As a convenient starting place for the weaving trials, a 100 yard long warp was prepared from 30 denier, type 330 nylon yarns with 5 tpi twist, as in the standard 1.1 oz/sq yd canopy fabric, and was drawn-in at 100 ends per inch. Following preliminary trials in which loom settings were adjusted, eight experimental fabrics, using each of the stretch yarns in turn as filling, were produced under identical weaving conditions. Details of these fabrics, together with comments on their appearance and weaving performance, are given in Table 6.

TABLE 5

MECHANICAL PROPERTIES OF SELECTED EXPERIMENTAL YARNS

Yarn Designation	Denier[a,b]	Breaking Load[b] (gm)	Breaking Tenacity (grams/denier)
3-A- 50	39.6	180	4.55
3-A- 87	46.6	214	4.60
3-A-100	50.0	200	4.00
3-B- 50	55.8	323	5.81
3-B- 87	61.6	259	4.20
3-B-100	65.6	360	5.49
1-B- 87	65.4	314	4.79
4-B- 87	62.4	343	5.49

a. Found from the weight of a 90 cm length of yarn; length measured under 10 gm load.

b. Each value is the average of 5 measurements.

TABLE 6

DETAILS OF EXPERIMENTAL FABRICS

Warp	Filling Yarn	Comments
	96 Picks per Inch of:	
100 ends per inch of 30 denier nylon	3-B-50 3-B-87 3-B-100	All were satisfactory, but the fabric with the 3-B-100 yarn, which is the highest denier yarn used, was just on the limit of weavability
	1-B-87	Could not be woven satisfactorily. The high number of wrapping turns per inch led to excessive liveliness, and the filling yarn formed pigtails in the woven fabric.
	4-B-87	Initial loom settings worked out with this filling yarn. Loom bumped excessively at 100 ppi, but wove satisfactorily at 96 ppi.
	3-A-50 3-A-87 3-A-100	All the nylon fillings wove very well, and the fabrics were of very good appearance, though as a result of the smaller denier of the nylon filling yarns, the fabrics were quite open in the loom-state.

With the exception of 1-B-87 and 4-B-87, approximately 2 feet of fabric were produced with each filling yarn. Filling yarn 1-B-87, with the high number of wrapping turns per inch, produced a fabric with a very poor appearance as a result of pigtails which formed in the filling yarn, and only a few inches of fabric were produced. Filling yarn 4-B-87 was used for all the initial loom adjustment and only about 9 inches of the final fabric was produced; accordingly, results for this material are not as complete as for the remaining six fabrics, for which a reasonable amount of fabric was available.

The fabrics showed varying degrees of stability when removed from the loom. All the B series fabrics, with the 44 denier polyester wrapping yarn, were almost completely stable, and showed only a very small shrinkage when removed from the loom. All the nylon A series fabrics, on the other hand, showed considerable tendency to shrink and only the 3-A-50 fabric, with the smallest denier of core yarn, retained a width close to the as-woven width; accordingly, no measurements were possible on fabrics 3-A-87 and 3-A-100 in the loom state. Some loom-state mechanical properties of the other fabrics are given in Table 7.

TABLE 7

PROPERTIES OF LOOM-STATE FABRICS

Fabric Designation	Weight (oz/sq yd)	Strength (lb/inch) Warp x Filling	Air Permeability at 0.5 Inch of Water (cu ft/min/sq ft)
3-B-50	1.3	46.2 x 64.0	218
3-B-87	1.5	49.5 x 64.7	176
3-B-100	1.7	52.0 x 56.7	177
4-B-87	1.5	55.5 x 52.5	178
3-A-50	1.3	47.5 x 60.2	302

The results of Table 7 show that all the fabrics were reasonably light in weight, and more than adequate in strength compared to the target of 40 lbs/inch, but that the air permeability at a pressure differential of 0.5 inches of water was much higher than the target of 100 cu ft/min/sq ft for all the fabrics, and controlled shrinkage is necessary to achieve the correct level of permeability. In an attempt to estimate the degree of shrinkage necessary, specimens of fabric were fully relaxed in hot water and a series of air permeability measurements were made with relaxed samples restretched to various extents. Results are given in Table 8, and are plotted in Figures 9 and 10. Figure 9 shows the complete set of results for the polyester filling yarns. The family of curves for the 3-B-50, -87 and -100 yarns show the expected trends, in that the fabrics with the heaviest filling yarns are less open, and have lower air permeabilities at all shrinkages, though the differences are not very marked. The fabric with the 50 denier core yarn showed the smallest shrinkage tendency; this behavior is in qualitative accord with the behavior of the nylon fabrics, in which the 3-A-50 fabric showed the minimum shrinkage on removal from the loom. The results for the 4-B-87 fabric show a slightly lower rate of change

of permeability with shrinkage than the 3-B series fabrics, particularly in the region around 100 cu ft/min/sq ft, indicating that this fabric has a somewhat less desirable characteristic for the particular application, though again the differences are small. In general, it appears that a shrinkage of approximately 25% should give polyester fabrics of the correct air permeability. The results for the single nylon fabric, 3-A-50 are shown in Figure 10. This fabric was the most open of the nylon fabrics and on the basis of the polyester results represents an upper limit of the permeability for these fabrics. In this case, a shrinkage of a little more than 30% is required to achieve the correct air permeability.

TABLE 8

AIR PERMEABILITY AT VARIOUS SHRINKAGES FOR EXPERIMENTAL FABRICS

Fabric Designation	Air Permeability at 0.5 Inch of Water Pressure Differential for Shrinkages* of: 0	10%	20%	30%	40%
3-B-50	281	166	172	--	--
3-B-87	236	180	148	92	69
3-B-100	232	166	131	95	87
4-B-100	282	205	155	101	62
3-A-50	396	298	205	131	79

$$\text{*Shrinkage} = \left(\frac{\text{Original Length} - \text{Relaxed Length}}{\text{Original Length}}\right) \times 100\%$$

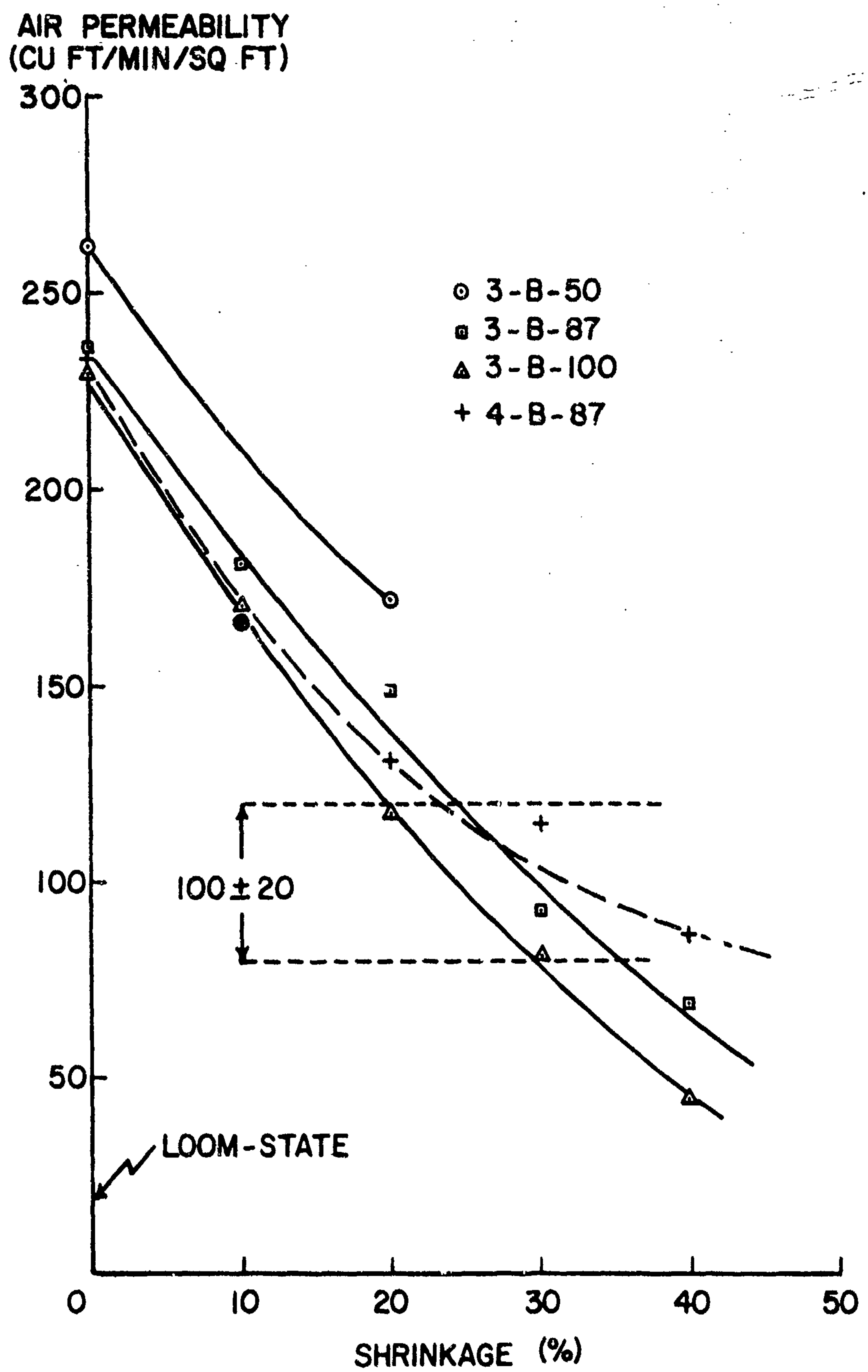


Figure 9. Variation of Air Permeability with Shrinkage for Polyester Filling Fabrics

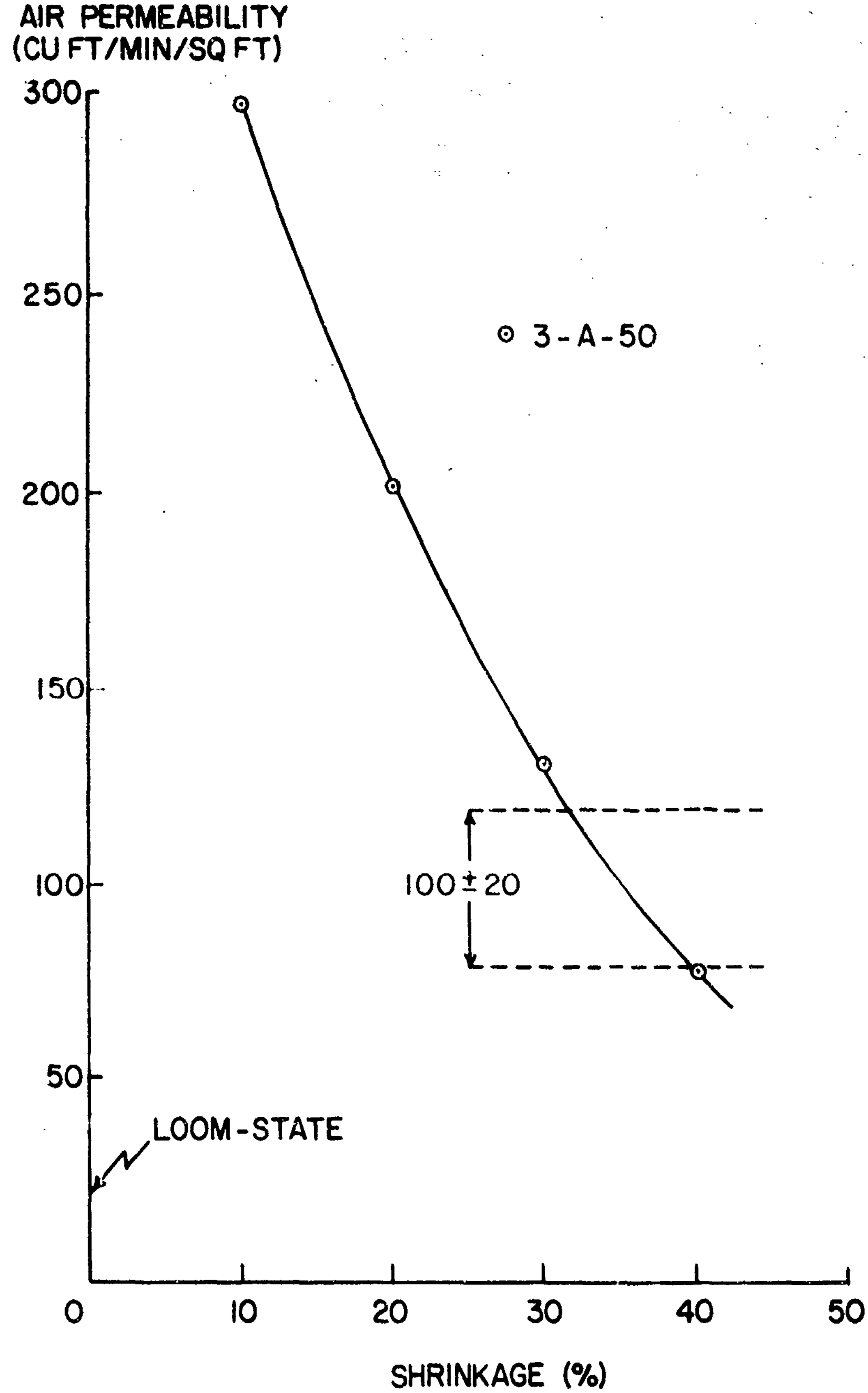


Figure 10. Variation of Air Permeability with Shrinkage for Nylon Filling Fabrics

Following the establishment of the approximate shrinkages required in the various fabrics, a series of heat-setting trials were carried out. Setting conditions were 350°F for 1 minute, with various amounts of shrinkage permitted. As a result of these trials, samples of set fabric with the correct permeability were produced. Constructional details of the fabrics are given in Table 9 and the complete air permeability characteristics are given in Table 10 and plotted in Figures 11 and 12.

TABLE 9

CONSTRUCTIONAL DETAILS OF HEAT-SET FABRICS

Fabric Designation	Ends/Inch x Picks/Inch	Weight (oz/sq yd)
3-B-50	174 x 117	2.06
3-B-87	169 x 118	2.09
3-B-100	169 x 118	2.26
4-B-87	- - -	2.20
3-A-50	207 x 118	1.92
3-A-87	216 x 118	2.21
3-A-100	191 x 118	2.11

These results indicate the superior performance of the fabric woven with the 50 denier core yarns, and also show that, for the particular fabrics woven the polyester fabrics are better than the nylon fabrics, though this could be a consequence of the fact that the same fabric constructions were used for both materials, even though the yarn deniers were different. With the information available, it seemed reasonable to concentrate future effort on the 3-A-50 and 3-B-50 yarns and to attempt to optimize the weaving and setting conditions for these fabrics. To this end, much greater lengths of experimental fabrics with these two filling yarns were produced for more extensive evaluation.

Approximately 20 yards of fabric were produced using the polyester wrapped filling 3-B-50, woven with 96 picks per inch. The filling yarn was then changed to the nylon-wrapped yarn 3-A-50, and following a period of experimentation on the loom conditions during which it was established that fabric woven from this yarn most closely fulfilled the permeability requirement with 128 picks per inch, approximately 20 yards of fabric were woven. Initial heat setting trials were carried out on these fabrics, using pin frames and a circulating hot air oven, and then short, but continuous, lengths of fabric were heat-set using the FRL laboratory coater. Considerable amounts of the loom state fabrics were consumed during these trials, but several yards of stable, heat-set polyester and nylon fabrics were finally prepared, and were comprehensively evaluated. Details of the evaluation are given in Table 11, where the properties of the two stretch fabrics are compared with the currently used 1.1 oz/sq yd nylon fabrics.

TABLE 10

AIR PERMEABILITY OF VARIOUS HEAT-SET FABRICS

Pressure Differential (in. of water)	Air Permeability (cu ft/min/sq ft) 1.1 oz/sq yd Fabric	3-B-50	3-B-87	3-B-100	4-B-87	3-A-50	3-A-87	3-A-100
0.5	111	102	106	98	104	101	101	98
1.0	192	184	205	176	182	175	181	169
2.0	314	333	306	288	315	296	307	276
4.0	484	565	491	474	525	484	505	452
6.0	630	778	662	641	732	651	706	608
8.0	756	966	832	800	892	811	832	756
10.0	872	1060 (9.0)	975	957	1036	957	984	892
11.0	-	-	1052	1044	1108	1044	1060	966
12.0	975	-	-	-	-	-	-	-

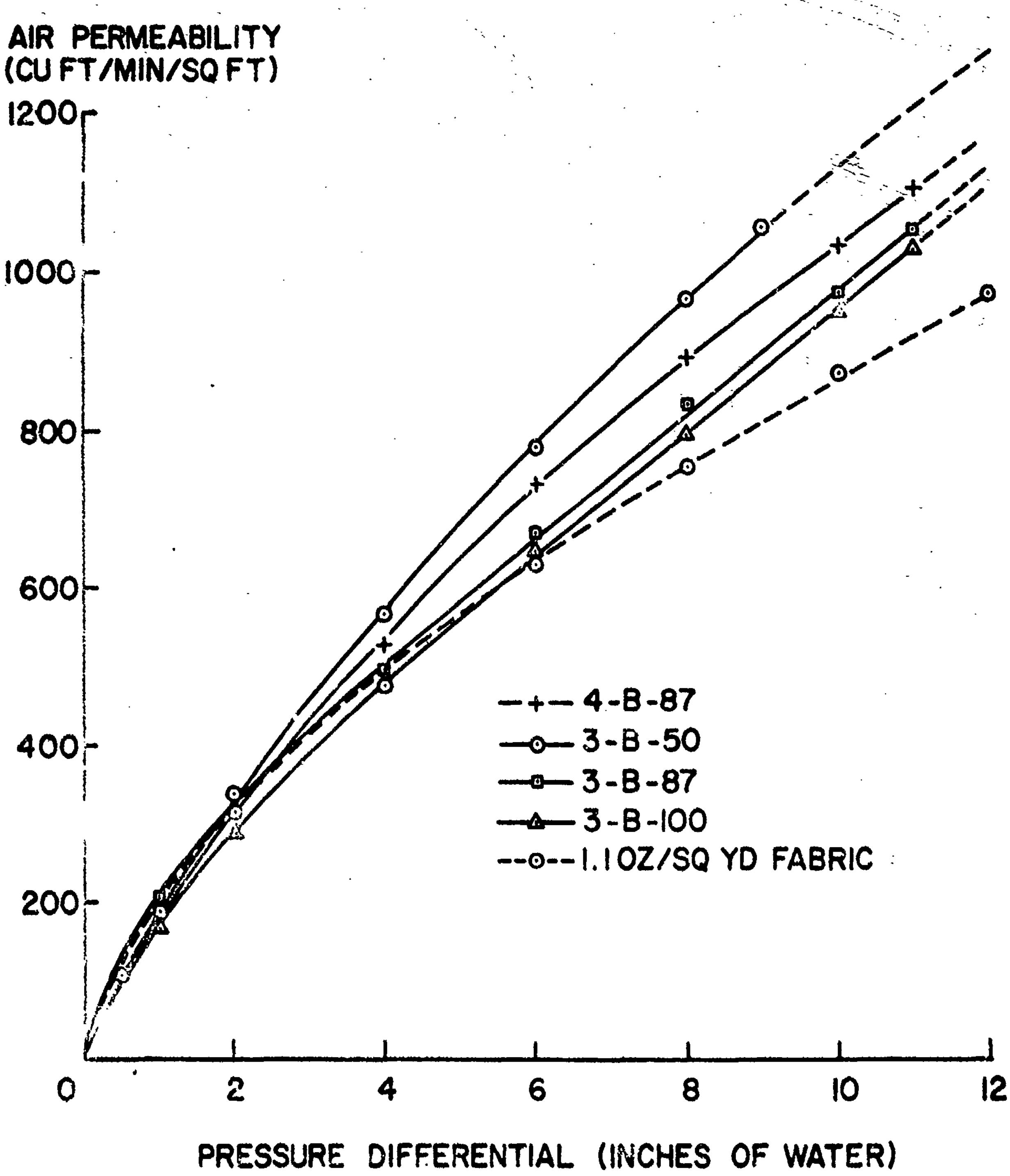


Figure 11. Variation of Air Permeability with Pressure Differential for Polyester Fabrics

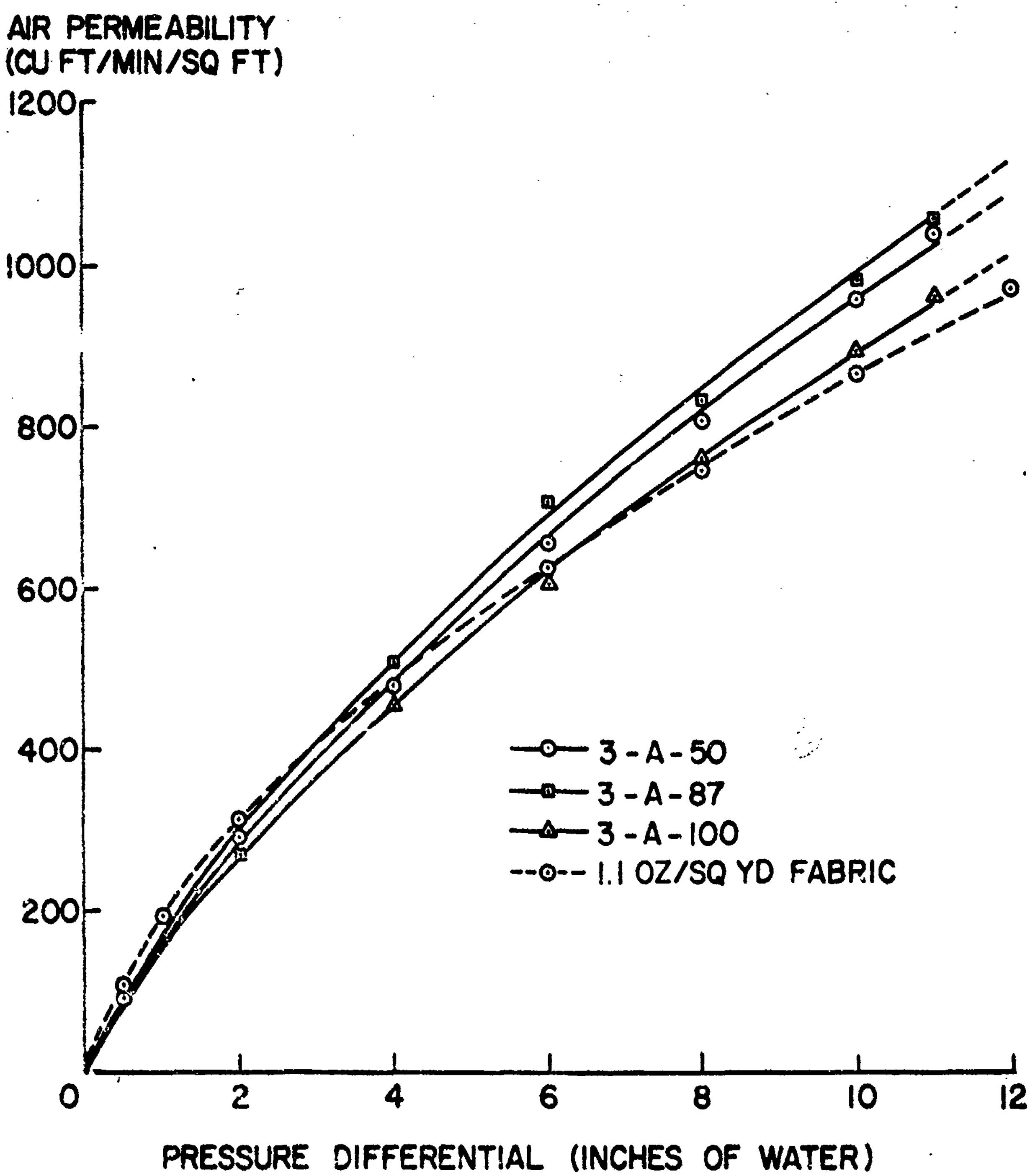


Figure 12. Variation of Air Permeability with Pressure Differential for Nylon Fabrics

TABLE 11

COMPARATIVE EVALUATION OF CANOPY FABRICS

Property	Regular 1.1 oz/sq yd Nylon Canopy Fabrics		Polyester/Spandex Stretch Fabrics		Nylon/Spandex Stretch Fabrics	
Construction (ends/inch x picks/inch)	120x120 Warp and filling yarns 30 den. HT nylon		159x104 Warp yarns 30 den. HT nylon Filling yarns 40 den. HT polyester/50 den. Spandex		152x135 Warp yarns 30 den. HT nylon Filling yarns 30 den. HT nylon/50 den. Spandex	
Weight (oz/sq yd)	1.1		1.9		1.7	
Air Permeability (cu ft/min/sq ft) at 0.5" H_2O	111		108		104	
12.0" H_2O	975		1139		1085 (11.5")	
	Warp	Filling	Warp	Filling	Warp	Filling
Tensile Strength (lb/in)	52.4	55.0	72.8	58.5	57.3	49.5
After exposure to 180°C for 1 hour (% Change)	47.3 (- 9.7	50.5 (- 8.7)	80.1 (+10.0)	33.7 (- 8.5)	54.5 (- 4.9)	48.3 (- 2.4)
After exposure to UV for 100 hours[a] (% Change)	44.3 (-15.4)	42.3 (-18.4)	57.8 (-20.6)	37.0 (-36.7)	--- ---	--- ---
Breaking Elong (%)	19.1	27.5	28.7	71.4	28.2	77.8

TABLE 11 (Cont)

COMPARATIVE EVALUATION OF CANOPY FABRICS

Property	Regular 1.1 oz/sq yd Nylon Canopy Fabrics		Polyester/Spandex Stretch Fabrics		Nylon/Spandex Stretch Fabrics	
	Warp	Filling	Warp	Filling	Warp	Filling
After exposure to 180°C for 1 hour (% Change)	19.8 (+ 3.7)	27.3 (- 0.7)	33.7 (+17.4)	106.5 (+49.2)	29.4 (+ 4.2)	62.0 (-21.3)
After exposure to UV for 100 hours (% Change)	19.0 (- 0.5)	23.7 (-13.8)	25.6 (-10.8)	66.9 (- 6.3)	---	---
Tongue Tear[b]	6.85	7.72	3.70	6.62	2.50	2.98
Elastic Recovery (%)[c] from deformations corresponding to loads of:						
1 lb/in	88	96	84	92	100	94
2 lb/in	87	97	89	89	100	94
4 lb/in	91	95	89	85	100	94
6 lb/in	93	95	90	86	100	94
8 lb/in	94	93	88	86	96	94

a. Exposed in Atlas FadeOmeter, Type FDS-R.

b. Median Upper Peak load.

c. Elastic recovery = [(Initial Strain-Residual Strain)/(Initial Strain)] X 100.

Both the polyester and the nylon fabrics are within the 2.0 oz/sq yd weight target set for the stretch fabric, and the tensile strengths of both fabrics are greater than the strength of the 1.1 oz/sq yd fabric. In particular, the strength of the polyester fabric in the warp direction is much higher than is necessary, mainly as a consequence of the high number of warp ends in this fabric. The strength losses on heat exposure are comparable to the standard fabric for the polyester, and somewhat less for the nylon. On exposure to UV the nylon warp in the polyester stretch fabrics suffered a 20.6% strength loss, a value which is in reasonable accord with the losses found in both directions in the 1.1 oz/sq yd fabric, which is woven from yarns nominally identical with those in the warp of the experimental fabrics. In the filling direction the polyester wrapped Spandex yarns suffered a 36.7% loss, but even with losses of this magnitude the final strength of 37.0 lbs/inch is very close to the target strength of 40.0 lbs/inch. No measurements were made of the UV degradation of the nylon fabrics, since all the available experimental fabric was used in other tests.

The tearing strength of the experimental fabrics was much lower than the tearing strength of the standard fabric, particularly for the nylon fabric. This deficiency is attributable to the lack of rip-stop yarns in the experimental fabrics, which increase the tearing strength of the 1.1 oz/sq yd canopy fabric from 2.5 lb to 6.5 to 7.0 lb. It seemed unlikely on the basis of these tests that the tearing strength of the experimental fabrics will reach the target of 4.0 lb without the incorporation of similar yarns, so a rip-stop modification was incorporated in all subsequent experimental weaving.

The elastic recovery behavior was found for deformations corresponding to load levels of 1, 2, 4, 6, and 8 lb/inch; because of the different tensile moduli involved these load levels correspond to different elongations in the various tests; this type of test duplicates to some extent the conditions existing in a deployed canopy, in which the strains adapt to a particular state of stress. The recovery for all the fabrics is extremely good even in this stress range; the strain range in question can be judged from the fact that at a load level of 2 lb/inch the experimental fabrics extend approximately 35%, while the standard fabric, and also the warp direction of the two experimental fabrics extend 2 to 3%.

Air permeabilities of all three fabrics are essentially identical at a pressure differential of 0.5 inches of water. At a pressure differential of 12 inches of water the polyester stretch fabric shows an increase of 17% over the 1.1 oz/sq yd fabric, and the nylon stretch fabric shows an estimated 15% increase. These increases are smaller than the target increase of 30%, but on consideration, it appears that this is a measure of the inadequacy of the test equipment rather than of the fabric. This is a most important issue, and deserves a more detailed discussion. Consider a fabric with one-way stretch potential clamped in a Frazier Air Permeometer, using the customary 2-3/4 inch specimen diameter. Under high pressure differentials, the fabric is subjected to biaxial tensile loads, and attempts to deform to accommodate this load. The only possible mode of deformation is out of the plane of the fabric, but since both sets of yarns must extend to accommodate this deformation, it is clear that the full stretch

potential of the filling direction cannot be realized unless the warp yarns can also extend. Since this is not the case in the unbalanced one-way stretch fabrics, only a very small fraction of the potential stretch is seen under high differential pressures, and the increase in permeability is much less than might be expected. The Frazier in its unmodified form is, then, only suitable for balanced fabrics, either stretch or non-stretch. For unbalanced fabrics, the behavior of the least extensible yarns will dominate the permeability performance. A much clearer picture of the effect of the fabric behavior under externally imposed biaxial load; some data to illustrate this behavior is presented later.

In overall balance of properties the nylon fabric comes closest to meeting the target requirements, and with the single exception of low tearing strength it compares favorably with the standard canopy fabric. Accordingly, a second nylon fabric incorporating rip-stop yarns was woven and heat-set. The weaving conditions were very similar to those used on the previous nylon fabric, but the warp yarns were drawn-in at 105 ends/inch, a little more densely packed than in the previous fabric, in an attempt to compensate for the additional openness created by the rip-stop elements. The fabrics was woven with 108 picks/inch of the 3-A-30 yarn. The weight, permeability and tensile behavior of this fabric was almost identical with those found for the plain weave fabric, but the tearing strength was increased to approximately 6.0 lb. Thus, this fabric met the target requirements of the investigation, and 10 yards were shipped to WPAFB for approval before large scale production of 2000 yards of fabric was started. Approval was subsequently received, and preliminary arrangements for the production procurement were initiated.

SECTION IV

PRODUCTION AND EVALUATION OF 2000 YARDS OF STRETCH CANOPY FABRIC

From the weaving of samples of fabric in one yard widths and ten yard lengths, under laboratory conditions, to the weaving of thousands of yards at commercial production speeds is a giant step, and can only be successful if the initial fabric design is fundamentally sound, and the production facility cooperates fully. FRL were fortunate in this particular procurement in obtaining the wholehearted cooperation of Debson Mills Inc., of New Bedford. Samples of fabric, approximate weaving conditions, and a quantity of 3-A-50 wrapped yarn, supplied as before from JRA Industries, were delivered to Debson. They obtained a warp of 30 denier HT nylon yarn and explored a variety of weaving conditions in order to find the optimum loom settings for commercial production of this particular fabric.

It was necessary to modify the initial drawing-in scheme, in order to avoid cumulative length differentials between the warp yarn in the plain weave and the rip-stop sections of the fabric, and it was eventually also necessary to replace the entire warp, since the quality of the original warp beam became progressively worse as weaving proceeded, and finally became so bad as to require constant attention in the loom. The new warp gave trouble-free weaving, and slightly more than 2000 yards of fabric were produced. Small samples of fabric were obtained by FRL for initial finishing trials on a laboratory scale; trials were then extended to full scale equipment at Debson's finishing plant, and with the finishing conditions finally established the entire 2000 yard run of fabric was finished. Constructional details and characteristics of the finished fabric are given in Table 12; seam strength and efficiency measurements were made by the Air Force Materials Laboratory, and are reported in the Appendix.

In view of its importance to the end-use application, and the unsuitable nature of the unmodified Frazier Air Permeometer for the measurement, considerable effort was spent in investigating the air permeability characteristics of the various fabrics studied in this program. Following discussion of the requirement with Air Force personnel it was decided to attempt to measure the air permeability under externally applied biaxial loads of up to 5 lb/in, these load levels representing as well as could be ascertained the loads in the deploying parachute. A Frazier Air Permeometer was modified to permit these measurements and the series of tests described in Table 13 was made.

Preceding page blank

TABLE 12

CONSTRUCTIONAL DETAILS AND CHARACTERISTICS OF FINISHED NYLON RIP-STOP STRETCH FABRIC

Property	Test Data for Fabric from Roll #2		
Ends/Inch x Picks/Inch	169 x 105		
Weight (oz/sq yd)	1.9		
Air Permeability at 0.5 inch H_2O Pressure Differential (cu ft/min/sq ft)	103		
	Warp	x	Fill
Tensile Strength (lb/in)	77.4	x	41.0
After exposure to 100°C for 1 hour	81.7	x	39.6
(% Change)	(+10.5)	x	(-3.4)
After exposure to 140°C for 1 hour	76.9	x	39.0
(% Change)	(-0.7)	x	(-4.9)
After exposure to 180°C for 1 hour	67.1	x	39.7
(% Change)	(-3.3)	x	(-3.2)
After exposure to UV for:			
25 hours	74.7	x	39.2
(% Change)	(-3.5)	x	(-4.5)
50 hours	69.6	x	38.4
(% Change)	(-10.1)	x	(-6.4)
75 hours	63.9	x	35.7
(% Change)	(-17.4)	x	(-13.1)
100 hours	62.5	x	33.3
(% Change)	(-19.3)	x	(-18.8)
Breaking Elongation (%)	35.7	x	116.3

TABLE 12 (Cont)

CONSTRUCTIONAL DETAILS AND CHARACTERISTICS OF FINISHED NYLON RIP-STOP STRETCH FABRIC

Property	Test Data for Fabric from Roll #2		
	Warp	x	Fill
After exposure to 100°C			
for 1 hour	36.4	x	126.2
(% Change)	(+2.0)	x	(+8.5)
After exposure to 140°C			
for 1 hour	34.5	x	111.0
(% Change)	(-3.4)	x	(-4.6)
After exposure to 180°C			
for 1 hour	32.9	x	89.4
(% Change)	(-7.9)	x	(-23.1)
After exposure to UV for:			
25 hours	33.2	x	113.6
(% Change)	(-7.0)	x	(-2.3)
50 hours	30.1	x	117.4
(% Change)	(-15.7)	x	(+0.9)
75 hours	26.5	x	108.3
(% Change)	(-25.8)	x	(-6.9)
100 hours	25.3	x	94.1
(% Change)	(-29.1)	x	(-19.1)
Tongue Tear (lb)			
(median peak load)	3.62	x	3.92
Elastic Recovery (%) from deformations corresponding to loads of:			
1 lb/in	100	x	94
2 lb/in	100	x	91
4 lb/in	100	x	88
6 lb/in	98	x	85
8 lb/in	96	x	82

TABLE 13

FABRICS AND EXPERIMENTAL CONDITIONS USED IN PERMEABILITY TESTS

Fabric	Nature of Loading	Direction of Loading	Measurements Made
Stretch Rip-Stop Fabric	1:1 Biaxial	Thread Direction	Variation of permeability with tensile load at various values of pressure differential
	1:1 Biaxial	Bias	
	Uniaxial	Filling Direction	
	Uniaxial	Bias	
Irving Stretch Fabric	1:1 Biaxial	Thread Direction	
	1:1 Biaxial	Bias	
	Uniaxial	Filling Direction	
	Uniaxial	Bias	
	1:1 Biaxial	Thread Direction	
1.1 oz/sq yd Fabric	Uniaxial	Filling Direction	
	Uniaxial	Bias	

Figure 13 shows the variation of permeability with biaxial load for the new stretch rip-stop fabric at 0.5 and 2.0 inches of water pressure differential. At higher values of pressure differential the flow through the fabric exceeded the capacity of the instrument at all levels of biaxial load. For a 1:1 biaxial load ratio the extension of the fabric should theoretically be independent of the direction of the applied stresses, and the close similarity between the permeability measurements of Figures 13 and 14 support this contention. Figure 15 shows the permeability behavior under uniaxial load oriented parallel to the stretch filling direction. The behavior under this load condition is very similar to that under biaxial load. This is a reflection of the fact that the observed changes in permeability are due almost entirely to geometrical changes caused by the elongation of the stretch filling yarns, and the effects of crimp interchange are minimized under these conditions. The effects of uniaxial bias loads are shown in Figure 16. There are two simultaneous effects on fabric geometry under these loading conditions; the angle between the two sets of yarns in the fabric changes when the fabric shears, thus reducing the open areas and hence the permeability. There is also an extension of the stretch yarns which tends to increase the permeability, in the same manner as was shown in Figure 15. The net effect of uniaxial bias stress depends on the detailed geometry of the fabric and yarn, and for the stretch rip-stop fabric there is a gradual reduction of permeability with increasing stress.

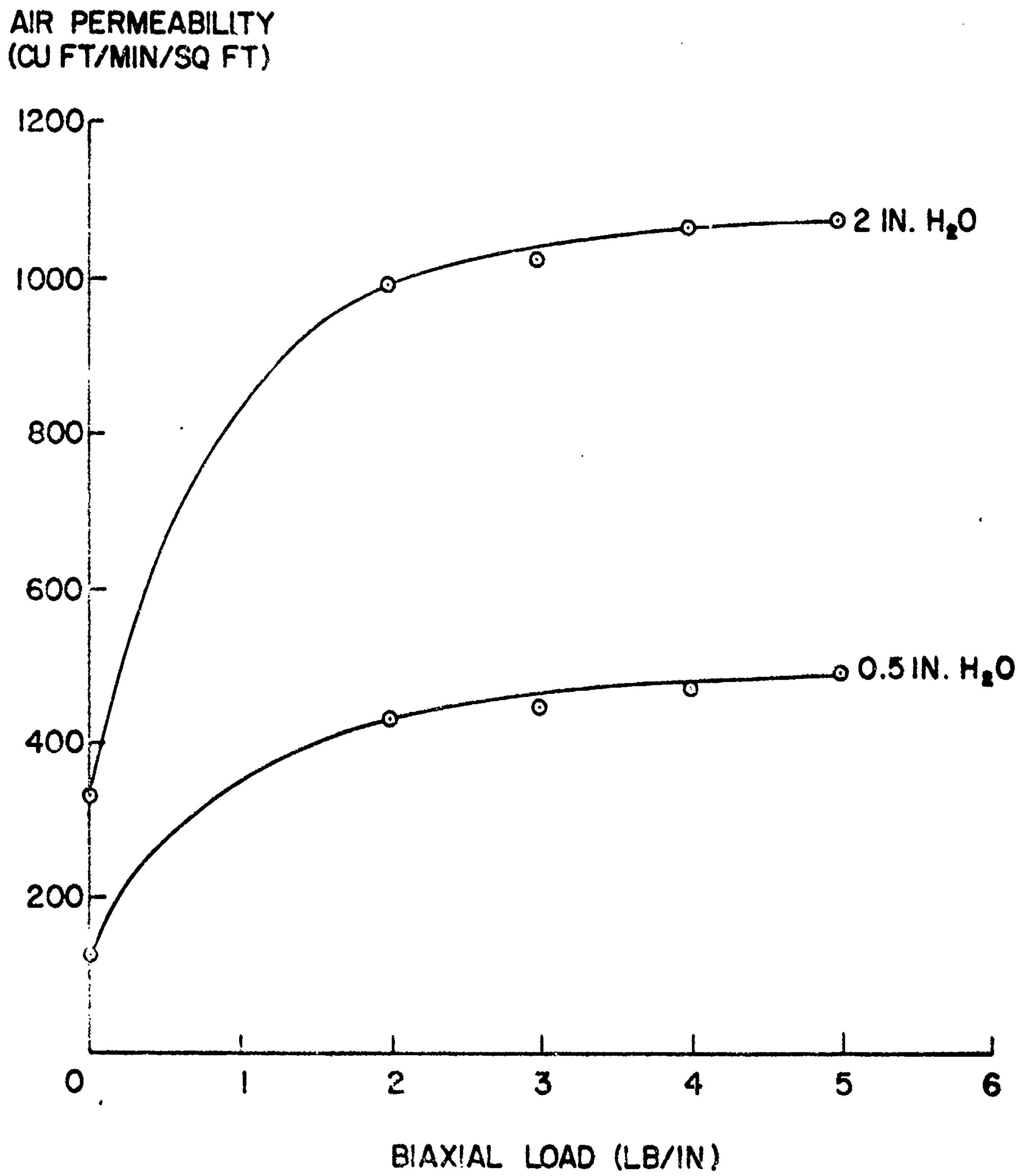


Figure 13. Variation of Air Permeability with Biaxial Load in the Thread Direction for the Stretch Rip-Stop Fabric

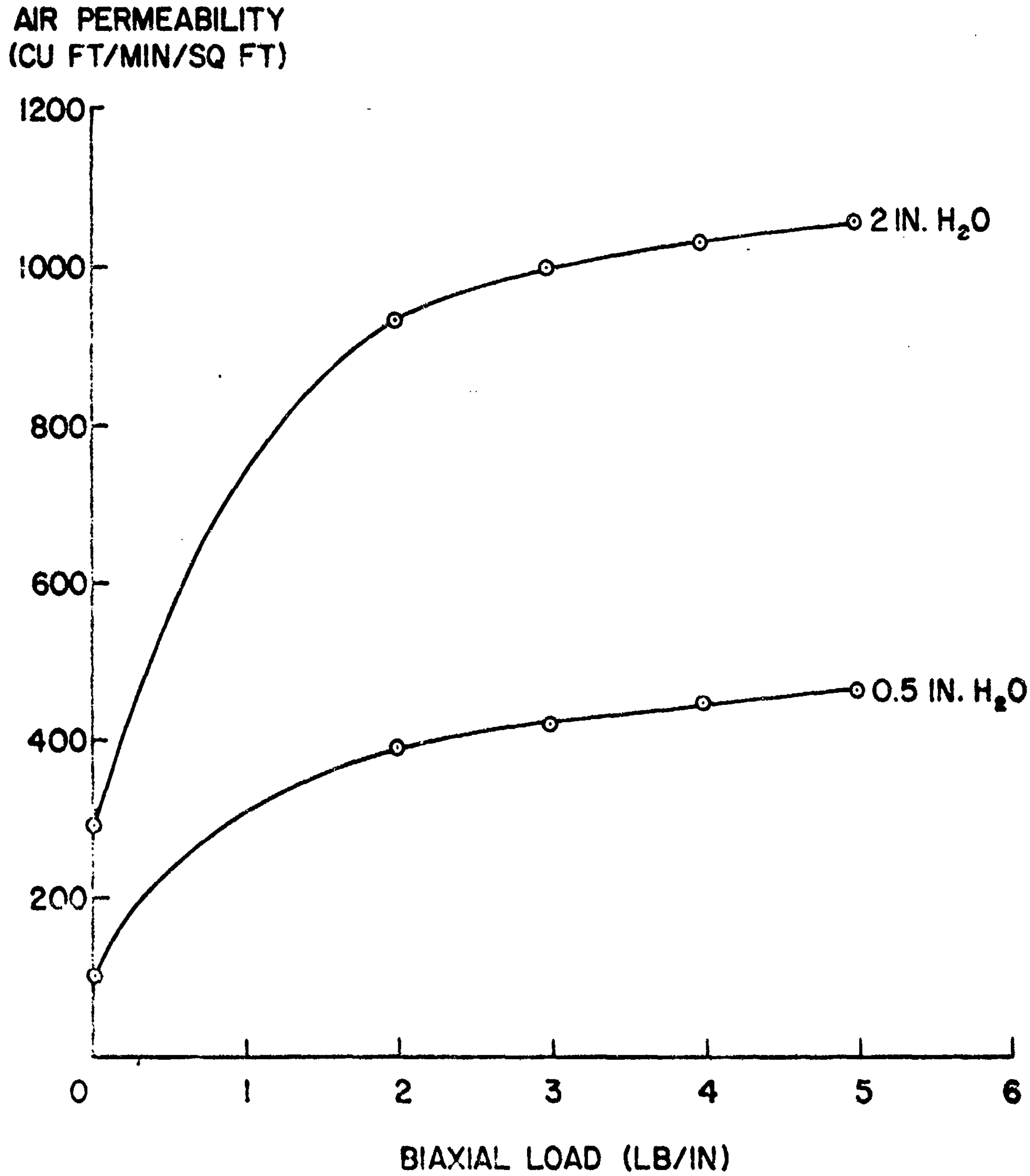


Figure 14. Variation of Air Permeability with Biaxial Load in the Bias Direction for the Stretch Rip-Stop Fabric

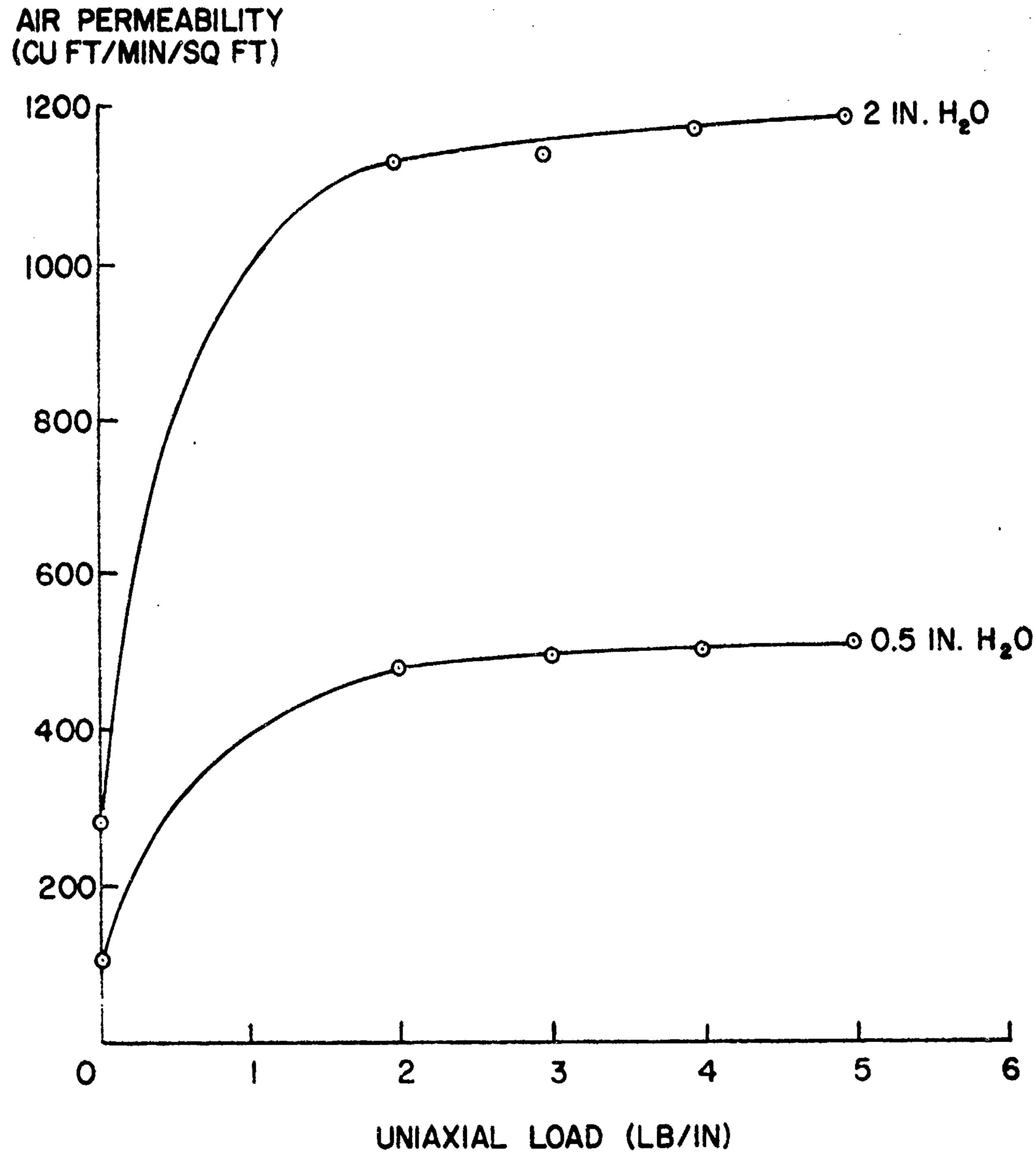


Figure 15. Variation of Air Permeability with Uniaxial Load in the Stretch Direction for the Stretch Rip-Stop Fabric

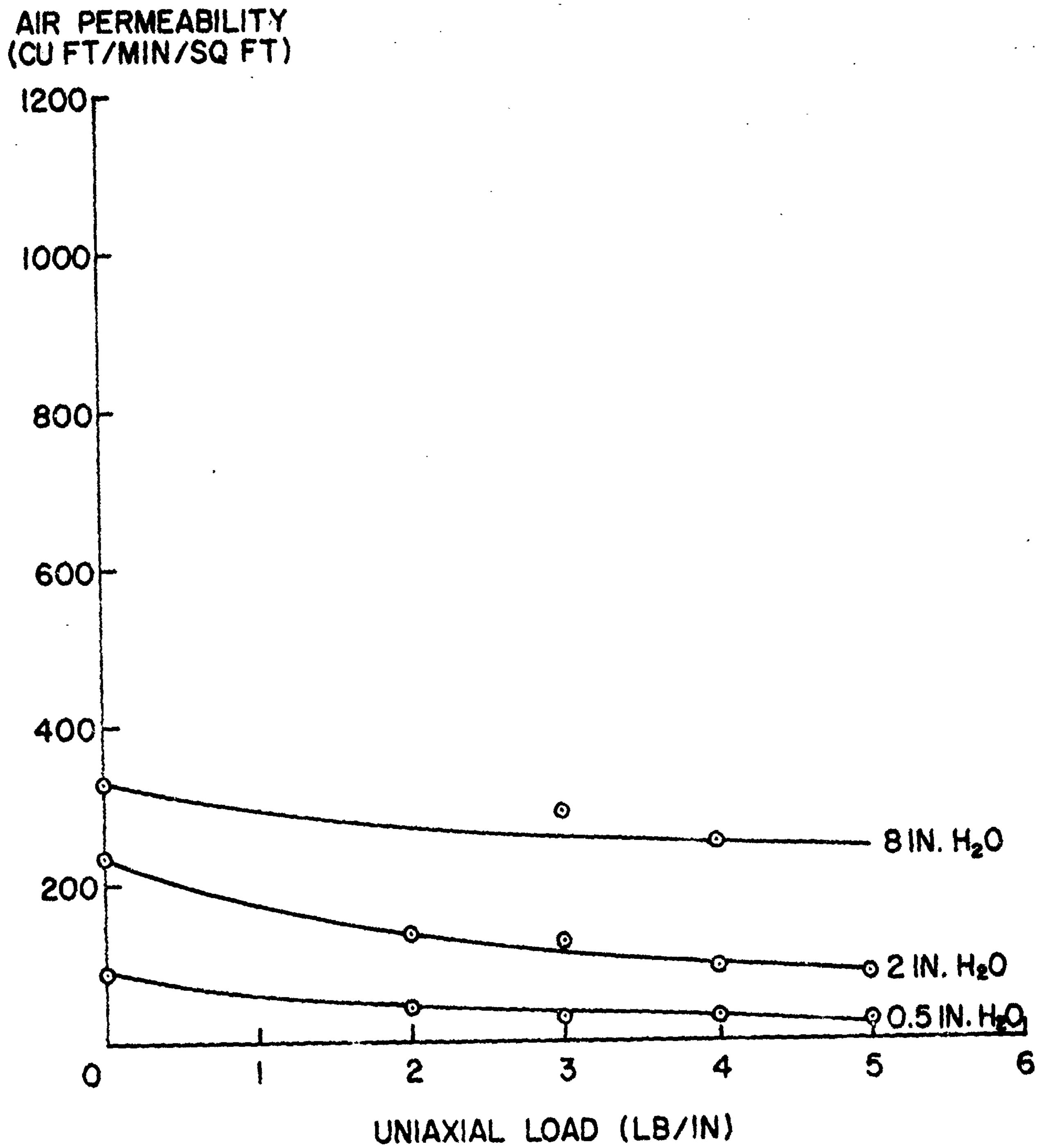


Figure 16. Variation of Air Permeability with Uniaxial Load in the Bias Direction for the Stretch Rip-Stop Fabric

The behavior of the Irving stretch fabric under a similar set of loading conditions is shown in Figures 17 through 20. Under biaxial load, the fabrics exhibit the characteristics discussed previously, though the general level of permeability is much lower than for the new fabric at given level of load and pressure differential, and initial rate of increase of permeability with biaxial load is not so rapid. Under uniaxial bias load, the Irving fabric shows a complicated variation of permeability with load, reflecting the multiple nature of the distortion mechanism. The general level of permeability under these load conditions is similar to that found in the new stretch fabric.

Figures 21 and 22 show for comparison purposes the effect of the various loading conditions on the permeability of the 1.1 oz/sq yd conventional fabric. In this fabric biaxial load and uniaxial load in the thread directions has a negligible effect on the permeability; under uniaxial bias loading only the shearing mechanism of distortion is possible, and there is a dramatic fall in permeability with increasing stress.

These experimental results point out clearly that the maximum benefit of the stretch fabrics will not be obtained if they are loaded in an essentially uniaxial manner in the bias direction; however, even if the stretch fabrics are used in this way they still show a considerable increase in permeability over the conventional fabric, whose permeability falls almost to zero under these load conditions.

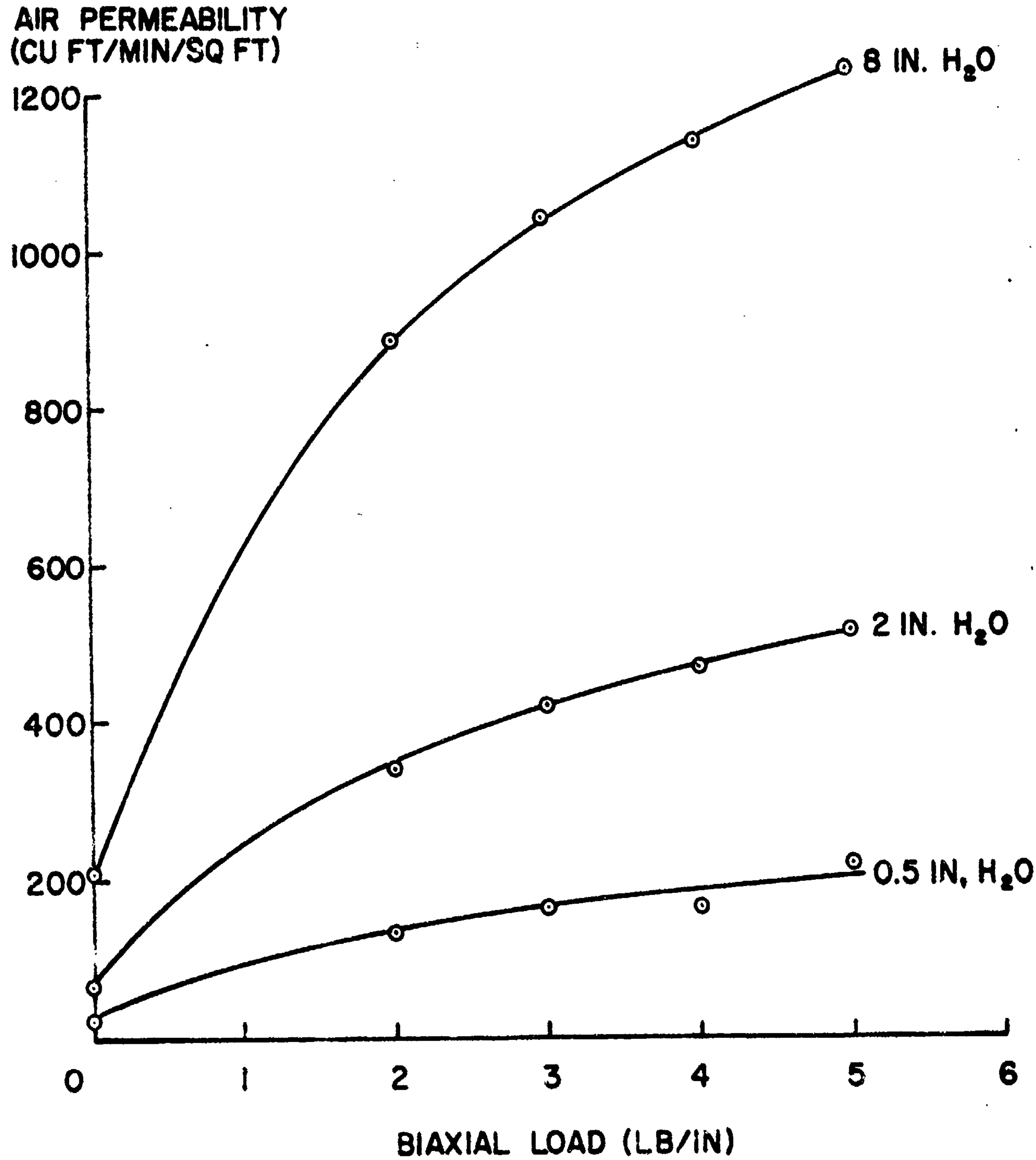


Figure 17. Variation of Air Permeability with Biaxial Load in the Thread Direction for the 3.6 oz/sq yd Stretch Fabric

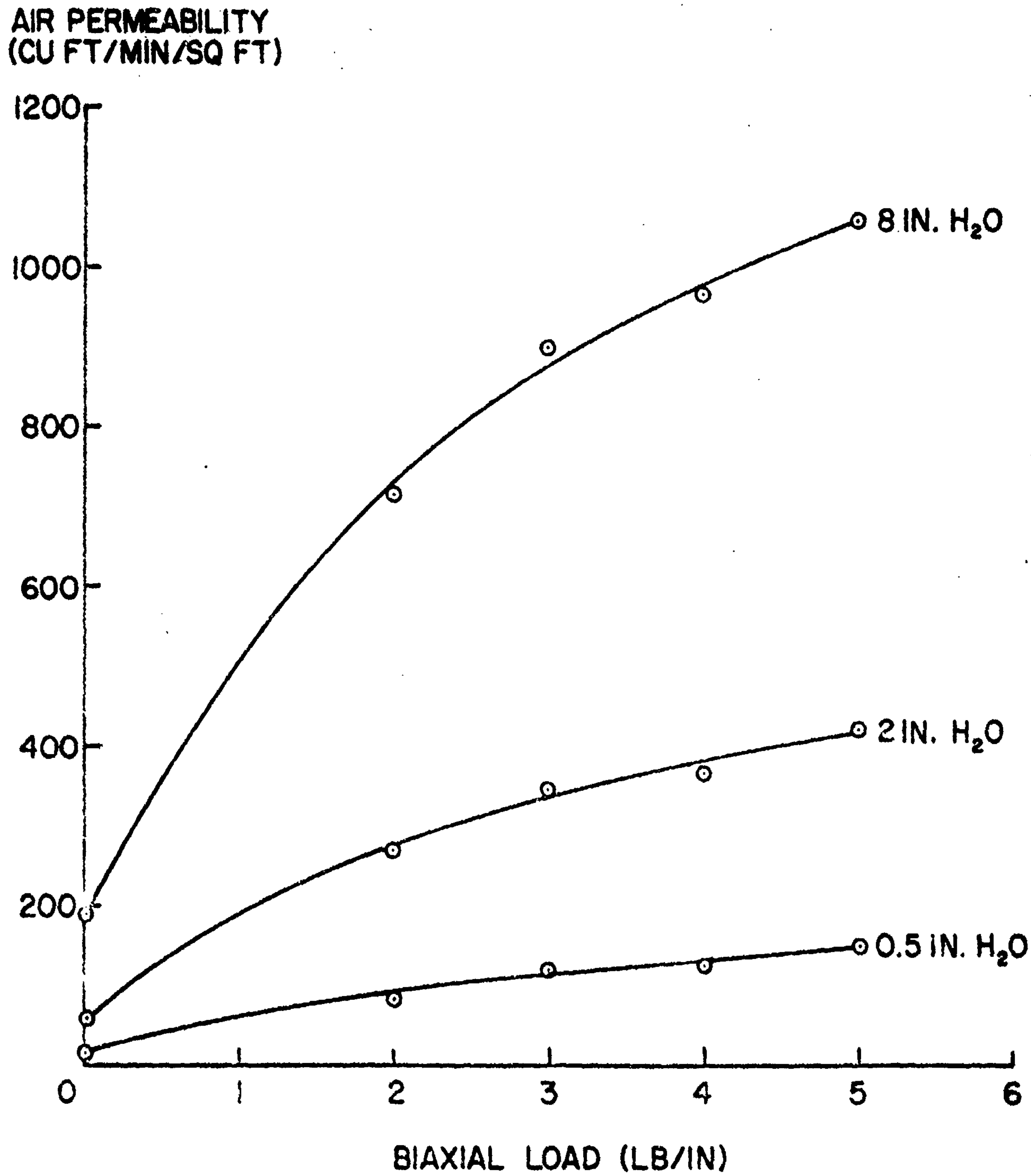


Figure 18. Variation of Air Permeability with Biaxial Load in the Bias Direction for the 3.6 oz/sq yd Stretch Fabric

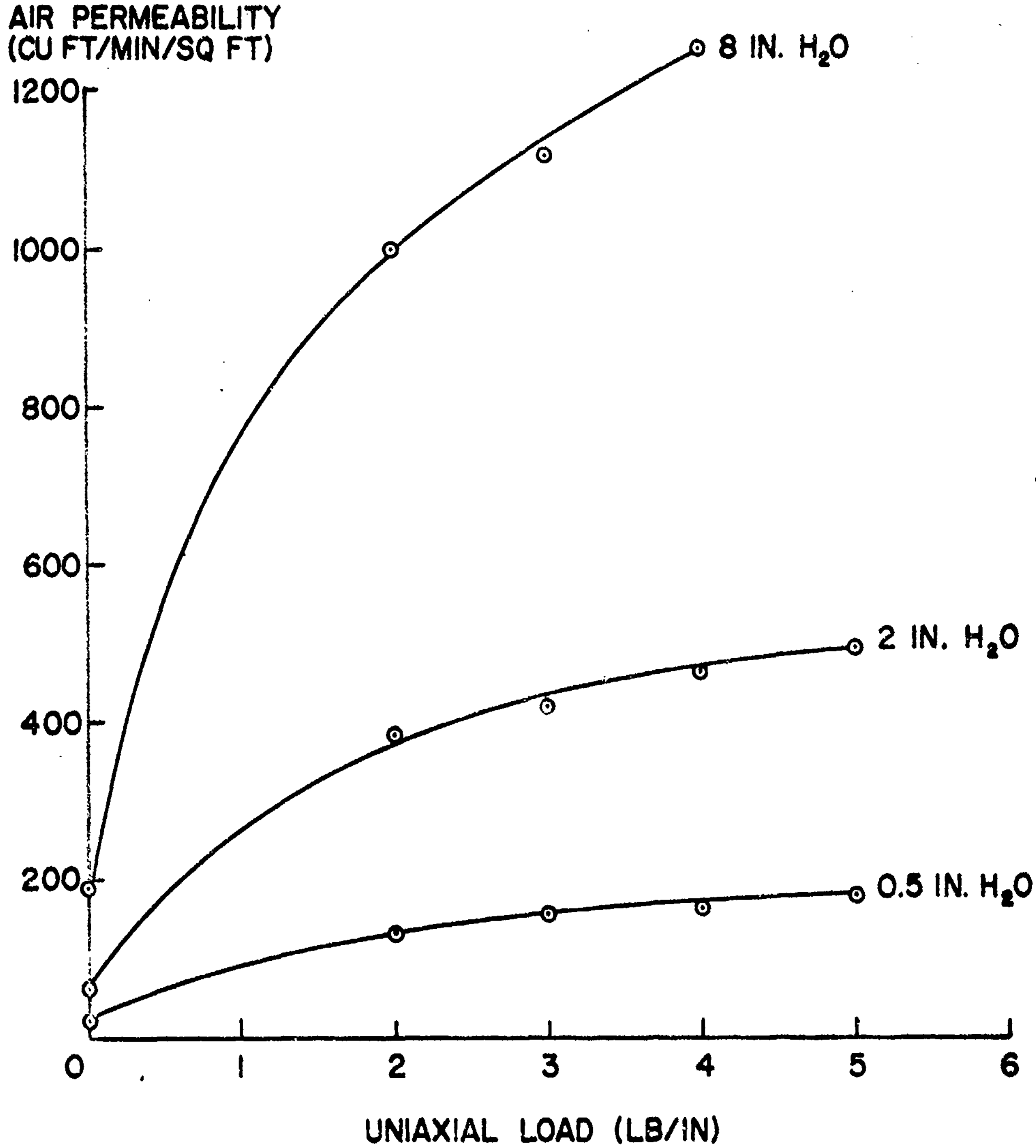


Figure 19. Variation of Air Permeability with Uniaxial Load in the Stretch Direction for the 3.6 oz/sq yd Stretch Fabric

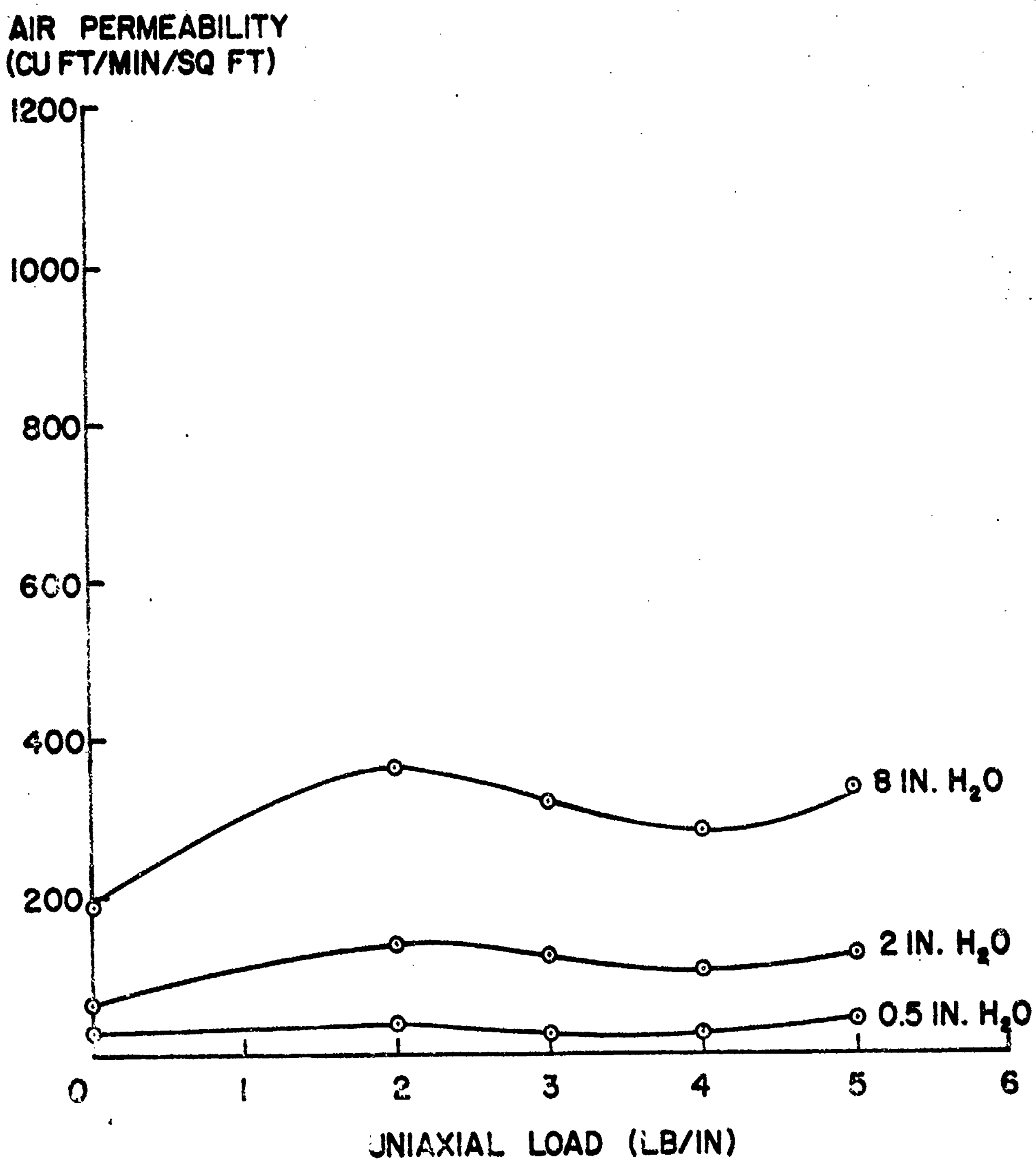


Figure 20. Variation of Air Permeability with Uniaxial Load in the Bias Direction for the 3.6 oz/sq yd Stretch Fabric

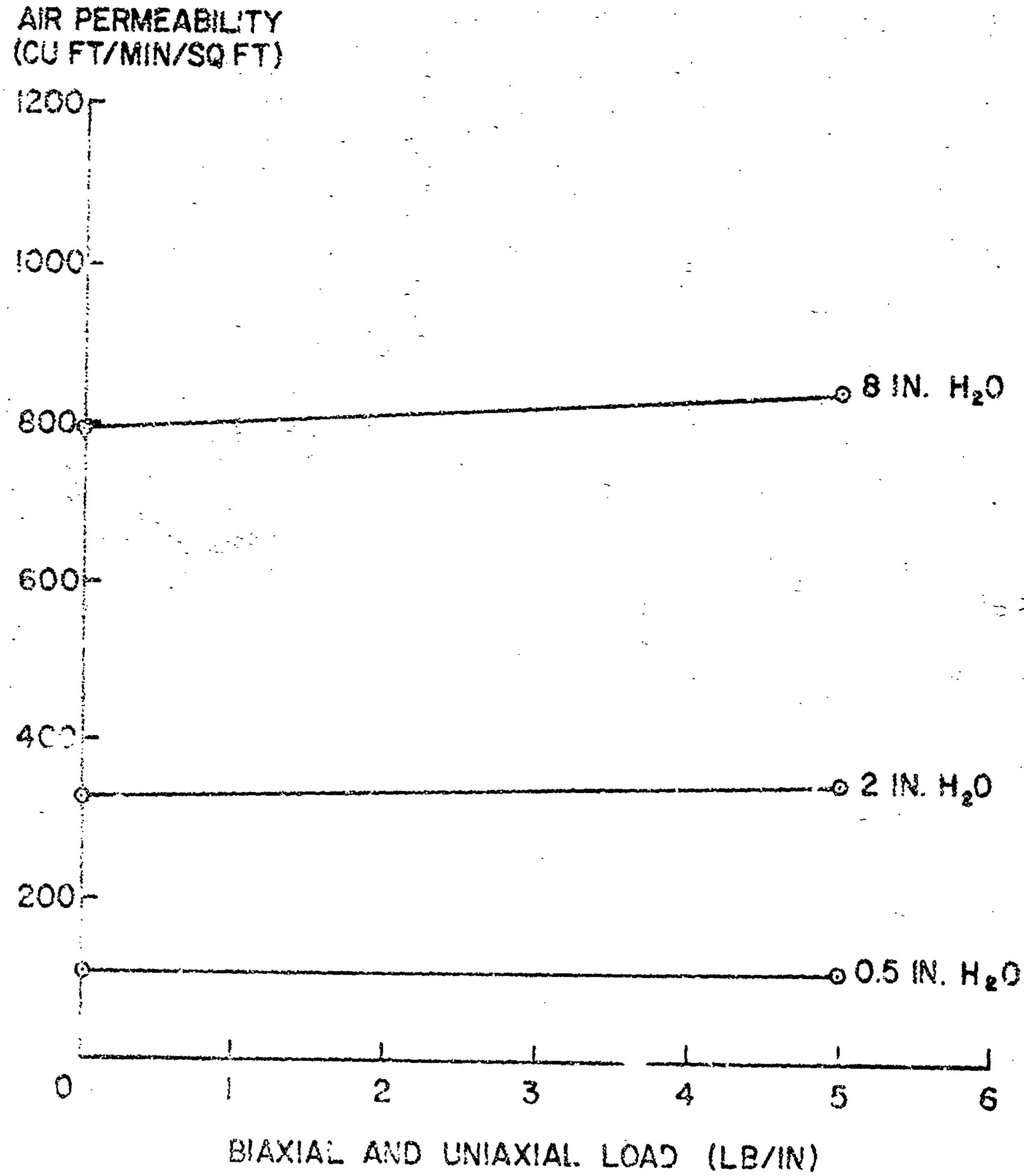


Figure 21. Variation of Air Permeability with Biaxial Load in the Thread Direction and the Bias Direction, and with Uniaxial Load in the Thread Direction for the 1.1 oz/sq yd Nylon Fabric

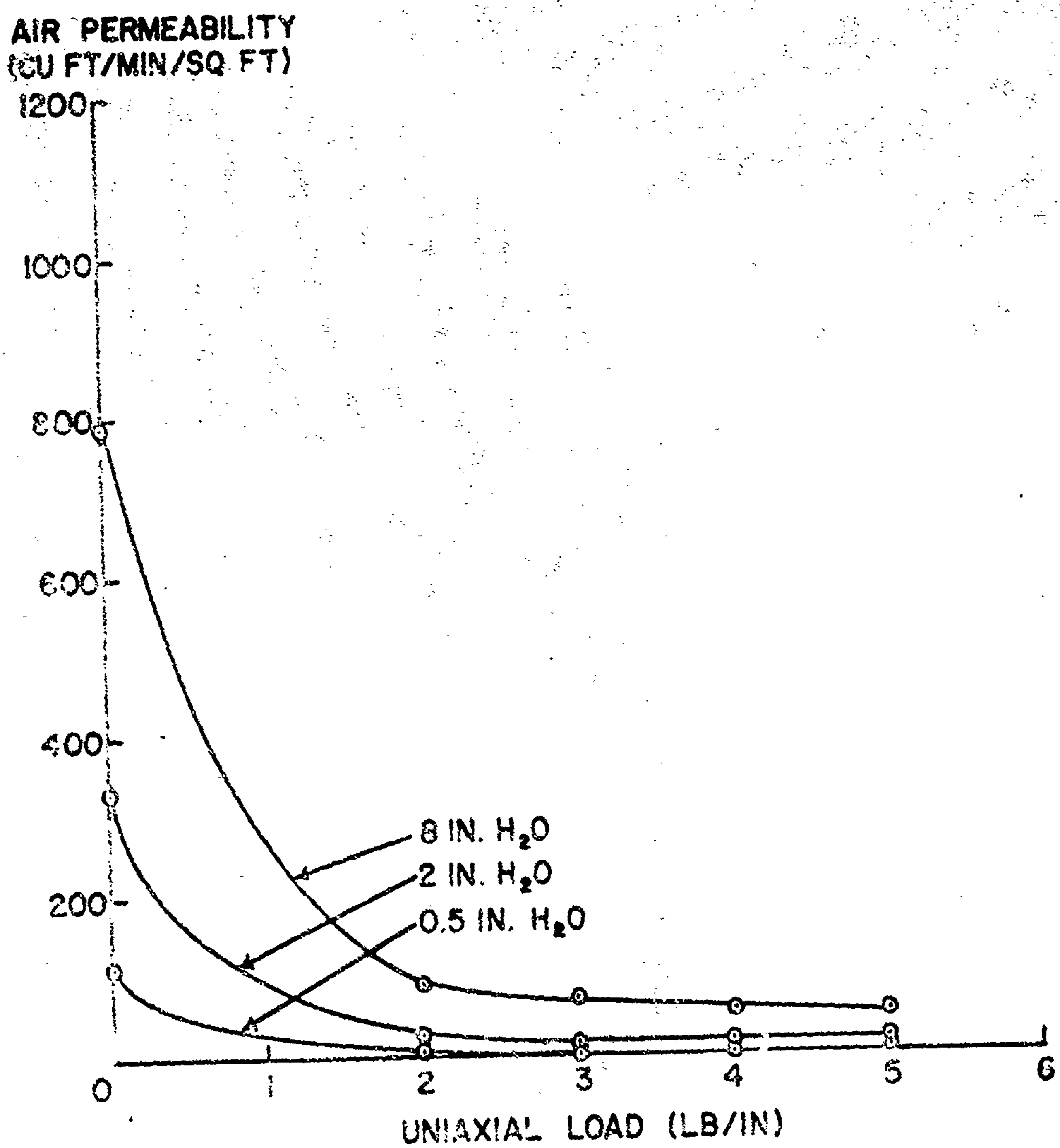


Figure 22. Variation of Air Permeability with Uniaxial Load in the Bias Direction for the 1.1 oz/sq yd Nylon Fabric

SECTION V

CONCLUSIONS

The one-way stretch fabric, utilizing nylon-wrapped Spandex filling yarn, which was developed during the course of this investigation fulfilled all the major requirements of the initial specification. In particular, the air permeability of the approximately 1.9 oz/sq yd stretch fabric under zero load conditions was very similar to that of the standard 1.1 oz/sq yd fabric currently used, and the strength and resistance to degradation was equal to that of the standard fabric.

Under biaxial loading conditions, the new fabric stretches in the filling direction, the inter yarn spaces became larger, and the air permeability increases: at a biaxial load level of 5 lb/in the permeability is approximately three times that of the conventional fabric, a factor which should lead to a significant reduction in the opening shock load in a parachute made from the new fabric.

Conventional parachutes are made with the fabrics oriented in the bias direction in the gore panels. This configuration permits a certain amount of dimensional accommodation during deployment as a result of fabric shear, but this accommodation is at the expense of decreased air flow through the fabric. Under similar loading conditions the new fabric shows an increase in permeability, but the maximum benefit can only be obtained by orienting the fabric so that the direction of easy stretch is aligned with the direction of principal stress in the canopy. It is recommended, therefore, that careful consideration be given to canopy design in order to take full advantage of the unique properties of the new fabric.

Preceding page blank

REFERENCES

1. "Dynamic Decelerators Using Variable Porosity Knit Fabric and High Elongation Suspension Lines", H.E. Brockman and J.D. Boone, AIAA Paper No. 70-1185, September 1970.

2. "Report and Evaluation: Industry Search of Stretch Fabric", Irving Air Chute, Ltd., Report No. IR-01-102, Reference CIP-65-C-19, to the Canadian Department of Defense Production, 1966.

3. "Performance Evaluation of Type C-9 Parachute Canopies Modified to Incorporate Nylon Stretch Fabric Section", R.H. Puddycomb, Air Force Flight Test Center, Technical Report 69-40, October 1969.

Preceding page blank

APPENDIX

EVALUATION OF SEAM STRENGTH

Seamed specimens for evaluation were prepared by the Aeronautical Systems Division. Sections of stretch fabric and conventional nylon rip-stop (1.1 oz/yd^2) fabric were joined together with a two row type LSC-2 seam using a 301 stitch with 8 stitches/inch (Fed. Std. 751). This is the type of seam used in personnel parachute canopy construction to join adjacent panels within a gore. Fabric sections were oriented to provide six combinations of fabric direction (e.g., filling of stretch to 1.1 oz nylon, filling of stretch to warp of stretch, etc.).

The seamed specimens were tested for efficiency by the Air Force Materials Laboratory in accordance with Method 5110 of Federal Standard 191. Under this method four inch wide specimens across the seam were tested for breaking strength using the grab method. Unseamed fabric was also tested using the grab method to establish the relationship between the performance of seamed and unseamed fabric. Five specimens were tensile tested for each fabric seam combination. Tabulated below are the average values obtained:

Unseamed, 1.1 oz nylon rip-stop, warp - 63.5 lbs.

Unseamed, stretch fabric, warp - 91.1 lbs.

Unseamed, stretch fabric, filling, (stretch direction) 54.4 lbs.

Seamed, 1.1 oz nylon rip-stop, warp, to 1.1 oz nylon rip-stop, warp - 47.2 lbs.

Seamed, 1.1 oz nylon rip-stop, warp, to stretch fabric, warp - 45.9 lbs.

Seamed, 1.1 oz nylon rip-stop, warp, to stretch fabric, filling - 42.3 lbs.

Seamed, stretch fabric, filling to stretch fabric, warp - 40.2 lbs.

Seamed, stretch fabric, filling, to stretch fabric, filling - 53.7 lbs.

Seamed, stretch fabric, warp, to stretch fabric, warp - 67.2 lbs.

None of the seams pulled apart in the test, but fabric rupture usually occurred close to the seam.